

AD-A169 496

GUIDE FOR INSPECTION OF COATINGS APPLIED TO HYDRAULIC
STRUCTURES(U) CONSTRUCTION ENGINEERING RESEARCH LAB
(ARMY) CHAMPAIGN IL A BEITELMAN ET AL. APR 86

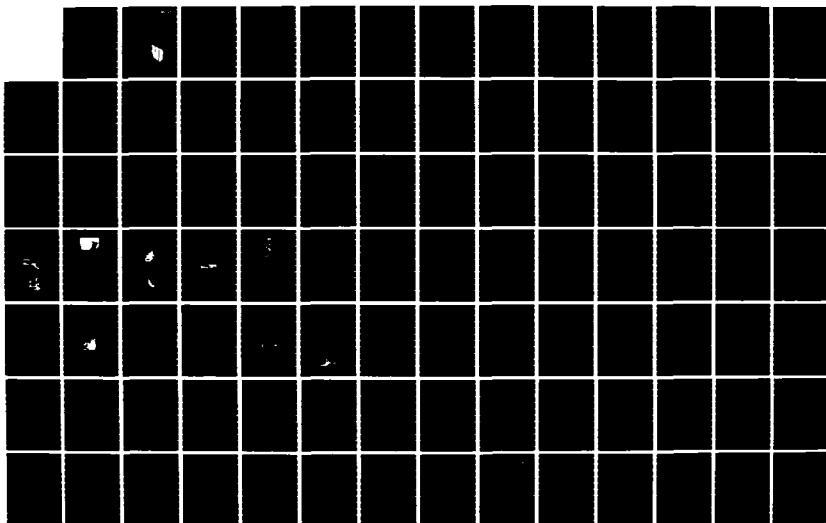
1/3

UNCLASSIFIED

CERL-TR-N-86/89

F/G 13/2

NL





CHART

2



**US Army Corps
of Engineers**

Construction Engineering
Research Laboratory

USA-CERL

TECHNICAL REPORT M-86/09
April 1986

AD-A168 486

Guide for Inspection of Coatings Applied to Hydraulic Structures

by

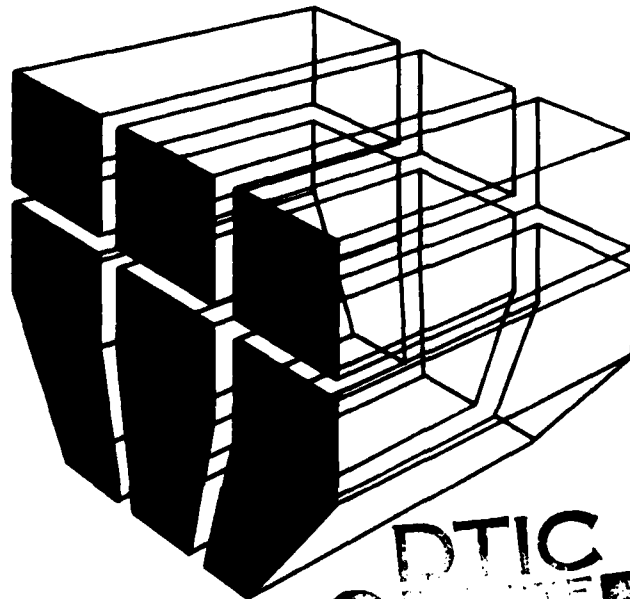
A. Beitelman

K. Tator

K. Trimber

E. Kline

This report contains instructional material for Corps of Engineers personnel who are responsible for inspection of coatings applied to hydraulic structures. Included is information on corrosion theory, coating types and characteristics, surface preparation, coating application, coating failures, inspection procedures for various types of coating systems, and use and calibration of inspection instruments. The information is intended to be used in implementing the guidance provided in Civil Works Construction Guide Specification CW-09940, *Painting: Hydraulic Structures and Appurtenant Works*.



DTIC FILE COPY

86 6 6 01 3

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL TR M-86/09	2. GOVT ACCESSION NO. ADA 168486	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Guide for Inspection of Coatings Applied to Hydraulic Structures		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. Beitelman K. Trimber K. Tator E. Kline		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Construction Engr Research Laboratory P.O. Box 4005 Champaign, IL 61820-1305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE April 1986
		13. NUMBER OF PAGES 224
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service Springfield, VA 22161		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) coatings inspection hydraulic structures locks (waterways) dams		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report contains instructional material for Corps of Engineers personnel who are responsible for inspection of coatings applied to hydraulic structures. Included is information on corrosion theory, coating types and characteristics, surface preparation, coating application, coating failures, inspection procedures for various types of coating systems, and use and calibration of inspection instruments. The information is intended to be used in implementing the guidance provided in Civil Works Construction Guide Specification CW-09940, <i>Painting: Hydraulic Structures and Appurtenant Works</i> .		

FOREWORD

This project was conducted for the Directorate of Civil Works, Office of the Chief of Engineers (OCE), under CWIS 31205 "Development of High-Performance Coatings." The OCE Technical Monitor was Mr. R. Kinsel DAEN-CWE-E.

The work was performed jointly by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) Engineering and Materials Division (EM) and KTA-TATOR, Inc., under contract to USA-CERL (DACW 88-84-C-0017). Messrs. K. Tator, K. Trimber, and E. Kline are associated with KTA-TATOR, Inc.

While much of the information presented in this document was taken from personal experiences, techdata sheets, and workshop information compiled by the authors, significant portions were received from other sources. We wish to gratefully acknowledge these sources. Through the courtesy of Dr. Richard W. Drisko of the Naval Civil Engineering Laboratory, much information and many slides from the "Painting of Facilities" training manual for the Air Force Engineering and Services Center were used. Selected slides in that document were graciously provided by Howard G. Lasser, a private consultant; C. G. Munger, a private consultant on coatings, formerly with the National Bureau of Standards; Lyle D. Perrigo of Battelle Alaska Operations; Dr. A. H. Roebuck of Flour Engineers and Contractors, Inc.; and Gil Hille of Graco, Inc.

Dr. R. Quattrone is Chief of USA-CERL-EM. COL Paul J. Theuer is the Commander and Director of USA-CERL and Dr. L. R. Shaffer is the Technical Director.

Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Dist _____	
Avail _____	
Date _____	
A-1	



CONTENTS

	Page
DD FORM 1473	iii
FOREWORD	v
LIST OF TABLES AND FIGURES	ix
1 INTRODUCTION	
Background	1-1
Objective	1-1
Approach	1-1
Mode of Technology Transfer	1-1
2 CORROSION THEORY	
Electrochemical Corrosion	2-1
The Basic Corrosion Cell	2-2
Galvanic Action	2-8
Corrosion Potentials and the Direction of Galvanic Effects	2-9
Techniques for Corrosion Control and Prevention	2-11
Protective Coatings	2-11
Design	2-12
Corrosion-Resistant Materials	2-12
Cathodic Protection	2-14
Inhibitors	2-14
3 COATING TYPES AND CHARACTERISTICS	
Drying Oil (Oleoresinous Paints)	3-1
Oil Base Paints	3-1
Alkyd Paints	3-2
Vinyl	3-2
Vinyl Butyral Wash Primers	3-2
Vinyl Chloride/Vinyl Acetate Copolymers	3-3
Catalyzed Epoxy Coatings	3-5
Coal Tar Epoxy	3-6
Bituminous Coatings (Cold Applied)	3-7
Zinc-Rich Coatings	3-7
Chlorinated Rubber Paints	3-9
4 SURFACE PREPARATION	
Importance of Surface Preparation	4-1
Methods of Surface Preparation	4-3
Solvent Cleaning	4-3
Steam Cleaning	4-3
Hand Tool Cleaning	4-3
Power Tool Cleaning	4-4
Water Blasting	4-5
Abrasive Blast Cleaning	4-7
Blast Cleaning Equipment	4-8
Air Compressor	4-8
Air Hose	4-9
Moisture and Oil Separators	4-11
Blast Pot	4-11
Blast Hose	4-12

CONTENTS (Cont'd)

	Page
Blast Nozzle	4-12
Safety	4-14
Respiratory Problems	4-14
Toxic Effects	4-15
Skin Disease	4-16
Burns	4-16
Eye Injury	4-16
Hearing Loss	4-17
Fire and Explosion	4-17
Equipment Accidents	4-17
Blast Cleaning Efficiency Checklist	4-18
Blast Cleaning Technique	4-19
Air Abrasive Mix	4-19
Angle of Attack	4-19
Nozzle-to Surface Distance	4-19
Size of Surface Area To Blast Clean at One Time	4-20
Abrasives	4-20
Size and Hardness	4-20
Abrasive Breakdown Characteristics	4-22
Shape	4-22
Storage	4-23
Quality Concerns During Blast Cleaning	4-23
Measuring Air Pressure at the Nozzle	4-23
Quality of Air Supply	4-24
Cleanliness of the Abrasive Material	4-24
Ambient Conditions	4-25
Standards of Cleanliness	4-25
Visual Standards	4-27
 5 COATING APPLICATION	
Brush Versus Spray	5-1
Paint Storage	5-1
Application Temperatures	5-2
Paint Viscosity	5-2
Mixing	5-3
Single-Package Mixing	5-3
Two-Component Mixing	5-4
Brushing	5-5
Paint Mitt	5-6
Rollers	5-6
Spray Painting - General Methods and Techniques	5-7
Choice of Paint Application System	5-8
Conventional (Air) Spray Painting	5-8
Airless Spray Paint Application	5-20
 6 INSPECTION	
Safety Considerations	6-1
Inspection Sequence	6-2
Pre-Surface Preparation Inspection	6-2
Ambient Conditions	6-3

CONTENTS (Cont'd)

	Page
Evaluation of Compressed Air Cleanliness and Surface Preparation Equipment	6-4
Determination of Surface Preparation, Cleanliness, and Profile	6-5
Witnessing Coating Mixing and Thinning	6-9
Inspection of Application Equipment and Techniques	6-9
Measurement of Wet Film Thickness	6-10
Determination of Dry Film Thickness	6-12
Magnetic Pull-Off	6-12
Fixed Probe Magnetic Flux Gages	6-16
Eddy Current Gages	6-20
Destructive Test Instruments	6-20
General Comments	6-22
Evaluating Cleanliness Between Coats	6-23
Pinhole and Holiday Testing	6-23
Test for Adhesion	6-26
Tests for Cure	6-26
 7 COATING FAILURES — CAUSES AND PREVENTION	
Improper Selection of the Coating System for the Service	7-1
Coating Failures Inherent Within the Coating	7-2
Chalking	7-2
Erosion	7-2
Checking	7-2
Cracking	7-2
Alligatoring	7-3
Mudcracking	7-3
Wrinkling	7-3
Micro-Organism Failure	7-3
Discoloration	7-4
Sulfide Discoloration	7-4
Pinpoint Rusting	7-4
Blistering	7-4
Peeling	7-6
Flaking and Scaling	7-6
Intercoat Delamination	7-6
Undercutting	7-7
Application-Related Failures	7-7
Atmospheric Conditions	7-7
Surface Preparation	7-8
Mixing	7-8
Thinning	7-9
Coating Thickness	7-9
Overspray	7-9
Pinholes	7-10
Spatter Coating	7-10
Holidays	7-11
Cratering	7-11
Bleeding	7-11
Blushing	7-11

CONTENTS (Cont'd)

	Page
Lifting	7-11
Orange Peeling	7-11
Runs or Sags	7-12
Design-Related Failures	7-12
Back-to-Back Angles	7-12
Skip Welding or Stitch Welding	7-12
Edges	7-12
Welds	7-13
Inside Corners	7-13
Discontinuous Areas	7-13
BIBLIOGRAPHY	Biblio-1
APPENDIX A: Daily Inspection Checklists for Concrete and Steel Substrates	A-1
APPENDIX B: Inspection Procedures for Various Paint Systems	B-1
APPENDIX C: Use and Calibration of Inspection Instruments	C-1
INDEX	Index-1
DISTRIBUTION	

TABLES

Number		Page
2-1	Galvanic Series of Various Metals Exposed to Seawater	2-10
2-2	Alloys Used Successfully in Marine Service	2-13
2-3	Galvanic vs. Impressed Current Cathodic Systems	2-15
3-1	Adhesion Characteristics of Paints Made with Copolymer and Vinyl Butyral Resins	3-4
3-2	Principle Advantages/Disadvantages of Frequently Used Industrial Coatings	3-10
4-1	Effect of Nozzle Pressure on Cleaning Rate	4-10
4-2	Air and Sand Consumption of Sandblast Nozzles	4-10
5-1	Application Rates by Method of Application	5-1

FIGURES

2-1	Anode and Cathode Hanging in Air	2-2
2-2	Anode and Cathode Suspended in Water	2-3
2-3	Open Switch	2-3
2-4	Closed Switch	2-4
2-5	Ionizing Water Molecules	2-4
2-6	Positively Charged Iron Ions	2-4
2-7	Direction of Electron Flow	2-5
2-8	Actual Direction of Current Flow	2-6
2-9	Corrosion Principle	2-6
2-10	Convening Ions	2-7
2-11	Hydrogen Gas Bubbles	2-8
2-12	Galvanic Action	2-9
3-1	Inorganic Zinc Protection	3-8
3-2	Agitation of Zinc-Rich Coatings	3-9
4-1	Sharp Edges	4-2
4-2	Pinpoint Rust Due to Excessive Profile Height	4-2
4-3	Needle Gun	4-4
4-4	Rotapeen Tool	4-4
4-5	Clean-N-Strip (3M)	4-5
4-6	Water Blast Equipment	4-6
4-7	Water Blasting During Use on Structural Steel	4-6
4-8	Abrasive Blasting	4-7
4-9	Centrifugal Blasting Machine	4-8
4-10	Basic Components of Open Nozzle Blast-Cleaning Apparatus	4-9

FIGURES (Cont'd)

Number		Page
4-11	Blast Pot--Gravity-fed	4-11
4-12	Straight Versus Venturi Nozzle Design	4-13
4-13	Open Nozzle Abrasive Blast Cleaning at Work	4-19
4-14	Angle of Attack for Various Degrees of Blast Cleaning	4-20
4-15	Nozzle-to-Surface Distance	4-21
4-16	Straight Pass of Blast Nozzle	4-21
4-17	Abrasive Shape	4-22
4-18	Hypodermic Needle Gage	4-23
5-1	Temperature Effect on Viscosity	5-3
5-2	Conventional Set-up	5-8
5-3	Conventional Spray Gun	5-11
5-4	Proper Spray Gun Stroke	5-15
5-5	Improper Spray Gun Stroke	5-15
5-6	Proper Overlapping Technique	5-15
5-7	Slender Work--Center Method Best for Most Jobs	5-17
5-8	Inside Corner Sprayed Square-on	5-17
5-9	Spraying a Panel	5-17
5-10	Spraying Round Work	5-17
5-11	Pole Gun	5-18
5-12	Nozzle Extension	5-18
5-13	Conventional Spray Paint Application Problems and Solutions	5-21
5-14	Common Airless Spray Problems	5-27
6-1	Testex Press-O Film Tape	6-8
6-2	Spring Micrometer	6-8
6-3	Notch-Type Wet Film Gage	6-10

FIGURES (Cont'd)

Number		Page
6-4	Mikrotest Magnetic Thickness Gage	6-13
6-5	Inspector Magnetic Thickness Gage	6-13
6-6	Pencil Pull-off Magnetic Thickness Gage	6-13
6-7	Magnetic Pull-off Gage Schematic	6-14
6-8	Effect of Foreign Material Within Paint Film	6-14
6-9	Mikrotest IV--Advanced Version	6-16
6-10	Minitector Magnetic Thickness Gage	6-17
6-11	Verimeter Magnetic Thickness Gage	6-17
6-12	GE Magnetic Thickness Gage	6-18
6-13	Elcometer 101 Magnetic Thickness Gage	6-18
6-14	Positector Magnetic Thickness Gage	6-19
6-15	Minitest Eddy Current Gage	6-20
6-16	Tooke Gage	6-21
6-17	Geometry	6-21
6-18	Low Voltage Wet Sponge Detector	6-24
6-19	DC High Voltage Detector	6-24
7-1	Blistering	7-5
7-2	Undercutting	7-8

GUIDE FOR INSPECTION OF COATINGS APPLIED TO HYDRAULIC STRUCTURES

1 INTRODUCTION

Background

The Corps of Engineers (Civil Works) is responsible for maintaining the locks and dams on navigable waterways as well as numerous smaller structures designed for flood protection or recreation. This maintenance includes repainting the existing steel structures. Most of the painting is done by private industry under contracts prepared using the Civil Works Construction Guide Specification CW-09940, *Painting: Hydraulic Structures and Appurtenant Works*. Inspection of these painting operations is the responsibility of the Corps.

In the past, improper inspection has resulted in the acceptance of paint work that did not meet specifications. Most of this has been attributed to insufficient inspection manpower, lack of training for inspectors, and insufficient or uncalibrated inspection equipment. It is believed that inspection efficiency could be improved by providing convenient reference material describing coating characteristics, proper application procedures, and equipment requirements.

Objective

The objective of this study was to prepare reference material to be used as a training aid for field personnel to implement the guidance provided in CW-09940.

Approach

Major sections discuss Corrosion Theory, Coating Types and Characteristics, Surface Preparation, Coating Application, Inspection, and Coating Failures. Appendix A contains daily inspection checklists for concrete and steel substrates; Appendix B details inspection procedures for various types of coating systems, and Appendix C discusses use and calibration of inspection instruments. An index is provided to help the reader locate specific topics.

Mode of Technology Transfer

It is recommended that the information in this report be made available to all Corps of Engineers personnel whose duties include the inspection of coating being applied to Corps hydraulic structures. The information may also form the basis for classes to instruct inspectors in thorough inspection of Corps painting projects.

2 CORROSION THEORY

Electrochemical Corrosion

Many articles written about corrosion are not specifically written for the layman. They assume a certain basic knowledge of chemistry and involve an understanding of chemical formulas that, although important and basic information, are very cumbersome for the layman inspector. Because an understanding of corrosion is very important for the coating inspector, and because it will provide him with a basic understanding of the importance of coatings and how they protect the steel substrate, this section will explain corrosion theory in basic terms.

To understand the process of corrosion, it is necessary to revert to the simplest elements of chemistry. A starting point is the atom, the smallest unit of all matter. One mil is equivalent to 109,000 atoms stacked on top of each other. Combinations of atoms coupled together make up all matter. An atom consists of a nucleus around which electrons travel. An analogy would be that the earth is the nucleus and the moon, an electron. The earth or nucleus contains gravity (positive charge) that keeps the moon from floating away. Because opposites attract, the moon in this case has a negative charge. In this analogy, the combination of the earth and moon together would be equivalent to an atom.

For the atom as a whole to have no charge, it must contain the same number of positive charges (protons) within its nucleus as it has electrons (negative charges) orbiting around it. An illustration would be that if an atom contains five electrons orbiting around the nucleus, the nucleus itself must contain five protons or positive charges in order to maintain the atom as a neutrally charged entity.

Specifically, in the case of iron, designated chemically by Fe, there are 26 protons in the nucleus and 26 electrons orbiting about the nucleus. When rusting occurs, however, some of the electrons are removed from the atom. The net result is that the iron atom now has an imbalance of protons and electrons (26 protons and only perhaps 24 electrons) which cause the atom itself to carry a positive rather than a neutral charge. This positive charge is written chemically as Fe^{++} or Fe^{2+} indicating that the imbalance is caused by two more protons (positive charges) than electrons (negative charges). If the designation were Fe^{+++} or Fe^{3+} , this would mean that three electrons have been lost and that the atom now contains three more protons than electrons. Any time an atom loses or gains electrons and changes from its normal neutral charge to either positive or negative charge, it is called an ion.

The understanding of only one additional chemical substance is required to understand the electrochemical corrosion process. Because the following examples use water to explain the process, one must also understand its basic makeup. Water is designated H_2O . This means that one molecule of water contains one atom of oxygen coupled with two atoms of hydrogen and is electrically balanced or neutral. Under certain conditions, the atoms of water will separate and carry positive and negative charges, in other words, become ions. The basic H_2O water molecule, when separated into ions, becomes H^+ and OH^- . There are still two H's and one O, except that the single H carries a positive charge and the OH combination stays together and carries the negative charge. Another way of writing the basic water formula, therefore, would be HOH. The significance of this will be explained in the following description of electrochemical corrosion.

The Basic Corrosion Cell

For metal loss to occur in the basic corrosion cell, there must be an anode, a cathode, an electrolyte, and a means of coupling the anode and cathode together. It is not necessary to understand what an anode and cathode are or where they come from, just to recognize that anodes and cathodes exist. Figure 2-1 shows an anode and a cathode hanging in mid-air. Note that nothing is happening to either.

Figure 2-2 shows the same anode and cathode suspended in a tank of water. The H_2O 's represent the molecules of water that are still tightly coupled together. Note again nothing is happening to the anode or cathode.

Figure 2-3 shows the anode and cathode again suspended in a tank of water with a wire attached to each containing an open switch in between.

If the switch were closed, one would have the four basic components required for a corrosion cell; that is, an anode, a cathode, an electrolyte (water), and a means of coupling the anode and cathode together (the wire).

Nothing is happening in this figure, however, because the switch is open.

Figure 2-4 shows what happens once the switch is closed. Iron atoms are beginning to break away from the anode designated by the triangles, and each triangle that has gone into the electrolyte (water) has resulted in an equivalent material loss of the anode. The atoms cannot go into solution, however, without something unusual happening. That is, the electrons escape from the atom causing that portion that has gone into solution to become a positively charged ion, designated Fe^{2+} (remember 26 protons and only 24 electrons causing the imbalance of 2+). Note at the same time the escaping electrons are moving in pairs from the anode through the wire to the cathode.

Figure 2-5 takes the process one step further. The reaction at the cathode (i.e., the migration of available electrons to this area) causes the water molecules to break down or ionize into H^+ and OH^- . Figure 2-6 shows the positively charged iron ions (the triangles coupling with two of the negatively charged OH^- ions from the water). Each

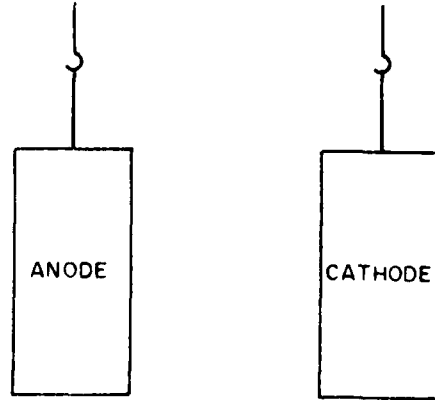


Figure 2-1. Anode and cathode hanging in air.

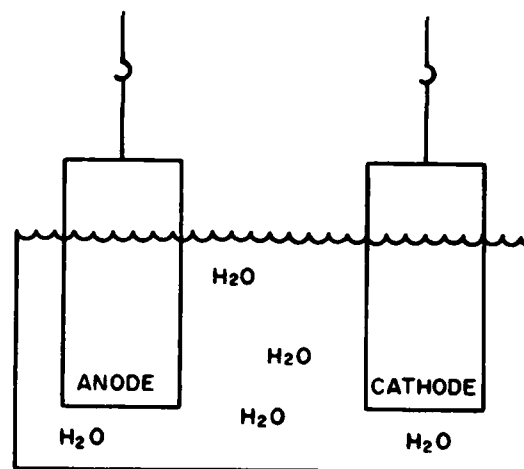


Figure 2-2. Anode and cathode suspended in water.

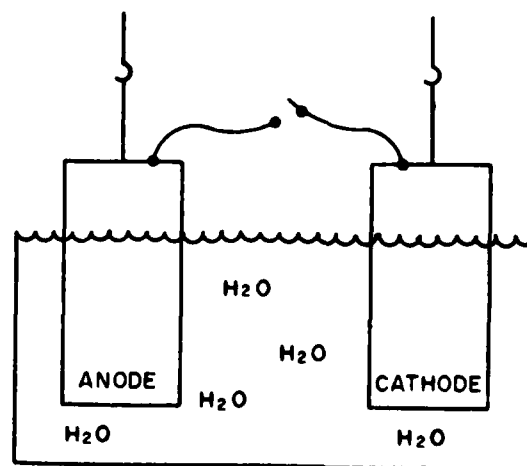


Figure 2-3. Open switch.

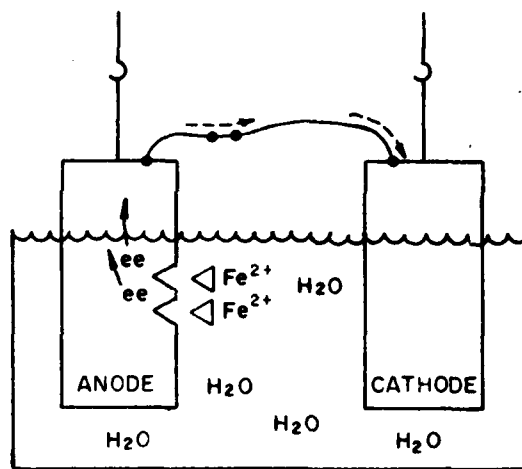


Figure 2-4. Closed switch.

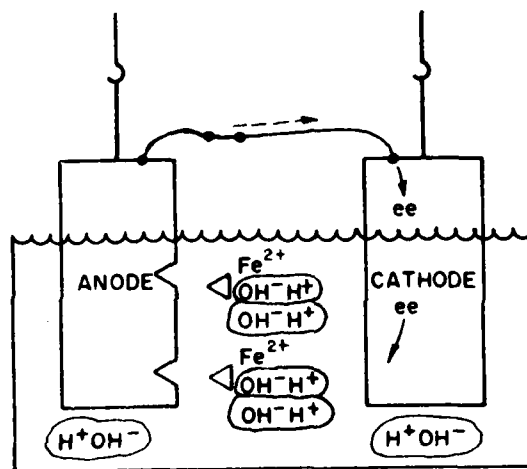


Figure 2-5. Ionizing water molecules.

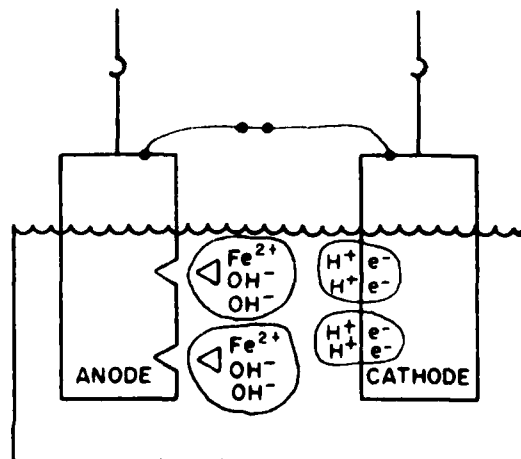


Figure 2-6. Positively charged iron ions.

iron ion couples with two of them because it contains two extra pluses (protons) and therefore strives to find two negative electrons to bring it into electrical balance once again. The electrons that have gone from the anode to the cathode through the wire go to the surface of the cathode and couple with the H^+ ions from the water. Once combined, they form hydrogen gas, which escapes as bubbles on the cathode.

In summary, the cycle begins with the iron going into the solution as a positive ion, at the same time releasing two electrons. The electrons automatically travel to the cathode, causing some of the water molecules to break down into ions. The positively charged iron ion combines with the negatively charged ions from the broken down water molecules, while the remaining positively charged ions from the water molecule combine with electrons on the cathode, forming hydrogen gas. This process will continue as long as the four components of the corrosion cell are present. The more that the iron ions go into solution, the more will be the metal loss at the anode.

In order for the corrosion cell to occur, there must be a current flow from the anode to the cathode, an electrolyte, and also a return path of that current from the cathode to the anode.

Figure 2-7 shows the flow you would expect after reading this and other materials related to corrosion theory. In other words, the arrow is carrying the current from the anode to the cathode through the electrolyte, and at the same time, the arrow shows the direction of the electron flow through the wire from the top of the anode to the top of the cathode. This diagram, however, although it appears to be logical, is unfortunately not commonly used.

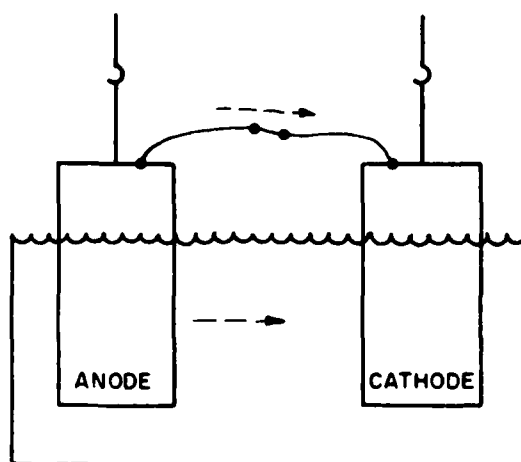


Figure 2-7. Direction of electron flow.

Figure 2-8 shows the actual direction of current flow according to popular convention. This agrees that the current flows from the anode to the cathode through the electrolyte. The difference, however, is that it shows the return path of the current through the wire to come from the cathode to the anode, contrary to the direction of the actual electron flow. The reason is not entirely clear, except that it is insisted, by convention, that the electricity flow in the external circuit (wire) run from positive to negative or cathode to anode.

Figure 2-9 illustrates the corrosion principle as it relates to the corrosion of metal. It shows a piece of metal and a solution of water. For illustration, the bottom is

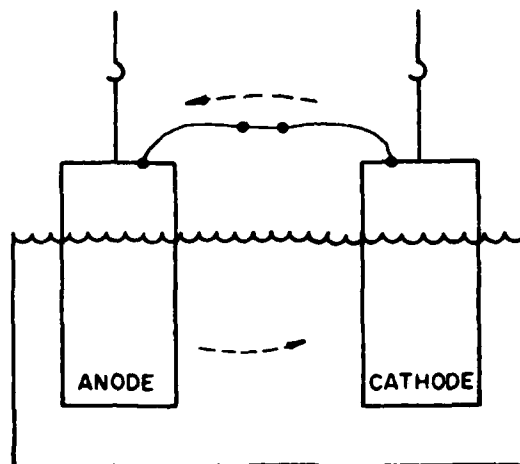


Figure 2-8. Actual direction of current flow.

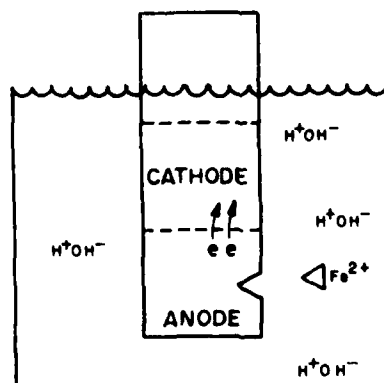


Figure 2-9. Corrosion principle.

being called the anode, while the next section above it is the cathode. The water is shown as H^+ and OH^- in its "broken down" ionic state, rather than H_2O . The iron is shown in its ionic state, Fe^{2+} in the solution, while the corresponding electron loss is shown moving through the metal up to the cathode. In this case, the connector between the cathode and the anode is the metal itself and not an external wire conductor as illustrated previously.

Figure 2-10 shows the iron ion coupling with OH^- ions from the water and the corresponding H^+ ions combining with the two electrons. Recall that their combination results in hydrogen gas.

Note that, in every case, when a reaction occurs at the anode (i.e., the iron ions leaving and going into the solution), an equivalent action must occur at the cathode. In other words, the cathode must be capable of receiving the released electrons from the iron. If for some reason the path for the electrons to travel is broken or the cathode can not receive those electrons because there are no H^+ ions at the surface of the cathode to couple with them, then this reaction will be slowed down considerably or conceivably even stopped.

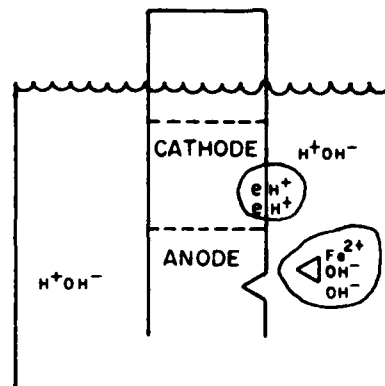


Figure 2-10. Convening ions.

Figure 2-11 shows what can occur if the above takes place. The bubbles on the surface of the cathode are hydrogen gas. Their presence slows down the current flow, and accordingly corrosion, by providing an insulating blanket over the cathode.

In the real world, however, when iron is exposed to water, the hydrogen blanket never has an opportunity to form completely. This is because water, other than pure water, contains dissolved oxygen which mixes with the hydrogen to form more water, thus breaking down and eliminating the hydrogen blanket. Therefore, oxygen turns out to be an essential element in the rapid propagation of corrosion.

The above discussion has described metal loss, not rust. To explain the actual formation of rust, it is necessary to follow the iron ions that went into the solution. The iron ions are coupled with the OH^- ions to form ferrous hydroxide, which is $Fe(OH)_2$. This will subsequently react further with oxygen available in the water to form ferric hydroxide, which is $Fe(OH)_3$, one common form of rust.

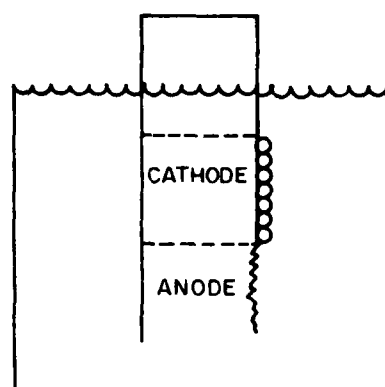


Figure 2-11. Hydrogen gas bubbles.

In two cases, the importance of oxygen in corrosion of steel has already been pointed out; that is, to remove the hydrogen blanket of the cathode and, second, to combine with the iron and OH^- ions to form the actual rust. Therefore, it should be obvious that by eliminating the presence of oxygen, one can reduce the rate of corrosion, and also that by eliminating the electrolyte, one can reduce or eliminate corrosion. Therein lies the importance of protective coatings in the prevention of corrosion. In general, the protective coatings will serve as a barrier between the steel and the elements, specifically oxygen and moisture.

The examples cited above have shown the anode and the cathode to be large, distinct areas, either within one steel segmented cell or as two separate segments attached by a wire. In reality, anodes and cathodes will exist on the same piece of steel side by side and can be so small and numerous as to be imperceptible to the naked eye. These areas, therefore, are definable only in the chemical sense. Some areas of the metal will act as an anode, while others will act as cathodes due to differences within the metal itself. These differences may be chemical in nature: inclusions in the metal, grain boundaries, differences in molecular composition, localized stresses, or even scratches, nicks, or other abraded areas on the metal surface.

If a piece of mild steel is placed in a solution of hydrochloric acid, a vigorous formation of bubbles (hydrogen) will be noted. Although the bubbles will appear to cover the entire surface, they are actually only occurring at the cathode where the hydrogen meets the released electrons from the anode. Although it may not look like it, these areas are very well defined. However, many times the anodic and cathodic areas will shift back and forth to give uniform corrosion. The reason the anode becomes a cathode and the cathode an anode is not important to an understanding of corrosion.

Galvanic Action

One metal may become an anode in total when it is in contact with a dissimilar metal. The term "galvanic action" is generally restricted to the changes in normal corrosion behavior that result from the current generated when one metal is in contact with a different one, and the two metals are in a corrosive solution (see Figure 2-12). In such a "galvanic couple," the corrosion of one of the metals (e.g. tin) will be accelerated

and the corrosion of the other (e.g. steel) will be reduced or possibly even stopped. Therefore, the first thing to be established is which of the metals will be affected one way and which will be affected the other. The answer is provided by the direction in which the electric current will flow from one metal (anode) to the other (cathode) in the corrosive solution as a result of a galvanic effect. The direction will be determined by the difference in the potentials of the two metals in the solution in question. In case of the aluminum/steel couple, the aluminum acts as the anode, and will therefore corrode, since corrosion takes place at the anode.

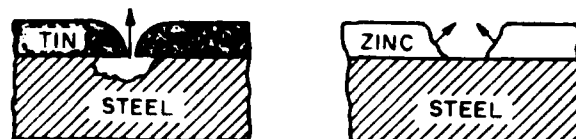


Figure 2-12. Galvanic action.

Corrosion Potentials and the Direction of Galvanic Effects

The potential of the metal on a solution is related to the energy that is released when the metal corrodes. Such corrosion potentials can be measured in at least a relative sense: for example, by placing a more reactive metal such as zinc and a less reactive metal such as copper in a solution of sodium chloride and measuring the direction and the voltage of the current generated by the galvanic action. Such an experiment can be repeated with all of the possible combinations of metals in any corrosive solution. Examination of the results would make it possible to arrange the metals in what could be called "galvanic series." If the experiments were to be repeated using a different solution, a different concentration of sodium chloride, a different degree of oxygen concentration, a different velocity of movement, or a different temperature, the voltage values that would be recorded would be different and the position of some metals relative to one other in such a "galvanic series" might be altered.

There is no absolute value of the electro-potential of the metal, independent of the factors that influence the corrosive characteristics of the solution in which the potential was measured. Values of potential can change from one solution to another or in any solution when influenced by such factors as temperature, aeration, and velocity of stirring. Accordingly, there is no way, other than by actual potential measurements in the exact environment of interest, to predict the potential of metals and the consequent direction of the galvanic affect in that environment.

However, in order to simplify the predictability of the galvanic couple, certain conventions have been adopted. The relative tendency of metals to corrode remains about the same in many of the environments where they are likely to be used. Consequently, their relative position in a "galvanic series" may be about the same in many environments. Since more observations of potentials and galvanic behavior have been made in seawater than in any other single environment, an arrangement of metals in a "galvanic series" based on such observations is frequently used as a first approximation of the probable direction of the galvanic effects in other environments (in the absence of data more directly applicable to such environments). Such a galvanic series is shown in Table 2-1.

Table 2-1
Galvanic Series of Various Metals
Exposed to Seawater

Active End:	Magnesium
	Magnesium Alloys
	Zinc
	Galvanized Steel
	Aluminum 1100
	Aluminum 6053
	Alclad
	Cadmium
	Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn)
	Mild Steel
	Wrought Iron
	Cast Iron
	13% Chromium Stainless Steel Type 410 (Active)
	18-8 Stainless Steel Type 304 (Active)
	18-12-3 Stainless Steel Type 316 (Active)
	Lead-Tin Solders
	Lead
	Tin
	Muntz Metal
	Manganese Bronze
	Naval Brass
	Nickel (Active)
	76 Ni-16 Cr-7 Fe Alloy (Active)
	60 Ni-30 Mo-Fe-1 Mn
	Yellow Brass
	Admiralty Brass
	Aluminum Brass
	Red Brass
	Copper
	Silicon Bronze
	70:30 Cupro Nickel
	G-Bronze
	M-Bronze
	Silver Solder
	Nickel (Passive)
	76 Ni-16 Cr-7 Fe Alloy (Passive)
	67 Ni-33 Cu Alloy (Monel)
	13% Chromium Stainless Steel Type 410 (Passive)
	Titanium
	18-8 Stainless Steel Type 304 (Passive)
	18-12-3 Stainless Steel Type 316 (Passive)
	Silver
Noble or Passive End:	Graphite
	Gold
	Platinum

In a galvanic couple involving any two metals on this list, the normal corrosion of the metal higher on the list will likely be accelerated, while the corrosion of the metal lower on the list is likely to be reduced or completely stopped. It should be noted that several metals are grouped together in the table. This is because the potential differences within the group are not likely to be great, and the metals can be combined without substantial galvanic effects under many circumstances. For instance, in the first group, magnesium and zinc can be combined with little, if any, galvanic effect.

Potential differences existing on pieces of the same or similar metal can also give rise to galvanic corrosion. Typical examples of galvanic corrosion are:

1. New steel is anodic to old steel
2. Steel is anodic to its surface mill scale
3. Freshly cut shiny surfaces (e.g., pipe thread) are anodic to uncut surfaces, and high stress areas (e.g., pipe bend) are anodic to less stressed areas.

Galvanic corrosion can usually be avoided by selecting compatible metals that must come in direct contact with each other in an electrolyte. If the metals cannot have the same composition (i.e., be the same metal or alloy), they should be close to each other in the galvanic series for this particular environment. It may also be possible to use either rubber or plastic insulators to avoid undesirable metal couples or to isolate the couple from the electrolyte. In addition, wrenches and other devices that cut into the metal should be avoided, and stressing should be minimized. In all forms of corrosion, the anode/cathode relationship is very important, as much more corrosion occurs when a small anode is in contact with a large cathode than in a reverse case.

Techniques for Corrosion Control and Prevention

Among the several techniques available for corrosion control are protective coatings, design, use of corrosion resistant materials, cathodic protection, and inhibitors. Each will be discussed separately. In an overall corrosion control system, these items are normally used in combination.

Protective Coatings

The chief means by which protective coatings impart protection to steel is by providing a barrier between the metal and the environment (i.e., oxygen and electrolyte). To prevent corrosion, the coating must be relatively impervious to water and salts, free of pinholes or other discontinuities, and thick enough to prevent the environment from coming in contact with the substrate.

A second protective mechanism is through the use of inhibitive pigments. Certain corrosion inhibitive pigments (i.e., chromate salts and lead), when properly formulated into a primer pigment, can deter corrosion should there be a break in the coating barrier.

The third way coatings deter metal corrosion is by a type of galvanic protection. A common example is a zinc-rich coating applied directly to steel.

In addition to conventional paints and coatings, barrier protection may also be imparted by greases, oils, and waxes.

Various coating types and their characteristics are explored in detail in Chapter 3.

Design

A significant percentage of corrosion problems are created by poor design. Design factors that affect corrosion include:

1. Geometry, orientation and environmental location
2. Compatibility of materials
3. Sharp edges and corners
4. Skip welds and other crevices
5. Configurations that permit water and salt collection
6. Abrasion or impacts
7. Velocity effects
8. Concentration cells
9. Erosion and fatigue
10. Cavitation
11. Galvanic differences
12. Temperature
13. Attack by corrosive gases
14. Stray current corrosion.

Each of these factors should be considered in designing a new facility. Details are not provided here, as design is outside the scope of this report.

Corrosion-Resistant Materials

There are many alloys which, when used properly, are quite resistant to corrosion. These alloys exhibit three types of corrosion behavior. Some are essentially immune to corrosion, while some corrode but at a rate significantly slower than steel. While some of these alloys are essentially corrosion free if properly used, they may corrode at extremely rapid rates if used improperly. Table 2-2 lists alloys that have been used successfully in marine service.

Several plastic or elastomeric corrosion-resistant materials are effectively used as substitutes for steel at certain instances. Uses for these materials include water and glass piping, hangers, grating, gutters, and downspouts. A list of some of these materials follows:

1. **Fiberglass Reinforced:** Lay-up of layers of fiberglass cloth or mat and polyester or epoxy resin. Properties: Strong and abrasion-resistant.

Table 2-2

Alloys Used Successfully in Marine Service

<u>Alloy</u>	<u>Properties</u>
Aluminum	Aluminum alloys are subject to marine pitting and crevice corrosion, especially in seawater; successfully used if pitting can be eliminated; lightweight.
Stainless Steel	Normally corrodes without special protection; marine grades of stainless steel (300 Series) usually corrode by crevice corrosion unless the crevices are avoided or cathodically protected. Grade 304 and 316 are most widely used.
Copper	Copper, cupro-nickel 90-10, cupro-nickel 70-30, and most true bronzes corrode at low rates in low-velocity marine waters.
Titanium	Essentially corrosion free except for stress corrosion in some alloys; chemically pure grades and heat-treatable alloys 6Al-4V annealed (100 ksi yield) are immune to corrosion in seawater and marine atmosphere; costly and very difficult to fabricate but strong and lightweight.
Nickel	Inconel alloy 625 and Hastelloy alloy C are immune to marine corrosion; Monel alloy 400 is usually immune if it can be cathodically protected.

2. **Plastics:** Spray-up of polyester or epoxy resins and chopped-up glass fibers. Properties: Strong and inexpensively fabricated.

3. **Foam-Urethane Material:** Foamed in place. Properties: Easy to use, but yellows and degrades in sunlight.

4. **Polystyrene:** Styrofoam cut to desired length and shape. Properties: Relatively inexpensive and weathers well.

5. **Plastic Wrap:** Flexible polyvinyl chloride sheets are water resistant but are readily damaged by impact.

6. **Rubber:** Natural or synthetic rubber molded to desired shapes. Properties: Has good impact resistance.

Cathodic Protection

Cathodic protection is a system for controlling corrosion of a metal surface by passing sufficient direct current onto it to make it a cathode, thus eliminating the possibility of anodic loss of metal. The electrolyte for cathodic protection is usually soil or water. It must be remembered that cathodic protection can prevent corrosion of a new structure or stop corrosion of an existing structure, but it cannot replace metal lost by corrosion of an existing structure.

There are two basic systems for providing the necessary direct current electrical energy to a structure to cause it to become a cathode. The basic practical differences in these systems will be shown later.

The galvanic anode system requires no external power supply. It incorporates anodes of a special alloy which are coupled to the structure. The necessary direct current is generated by virtue of the natural voltage between the anodes and the structure itself. The galvanic anodes (also known as "sacrificial") are consumed (like the anodes in a typical galvanic corrosion cell) in the process of generating current and thus have a limited service life. Galvanic anodes are fabricated from active metals and alloys; three basic materials are used--magnesium, zinc, and aluminum of high purity or other special composition.

The impressed current system uses low-voltage, high-amperage, direct current from an external power source. The positive terminal of the power source must be connected to the anodes, and the negative terminal to the structure to be protected. The relatively stable anodes used to discharge current have much longer service lives than galvanic anodes. These anodes can theoretically be made from any electrically conductive material. In practice, however, unless the material is inert in the environment, it will be consumed. High silicon cast iron, graphite, and aluminum are commonly used materials. Scrap iron, special lead alloys, platinum, platinum-palladium alloy, platinized titanium alloy, and platinized tantalum alloy are also occasionally used. Rectifiers are normally used to convert available AC power to the DC power needed to power the system.

It must be noted that there is a limit to the amount of bare steel that can be effectively protected cathodically. Once too much steel is exposed, the current demands will become too great for either system to function properly, and the cathodic protection is decreased or lost. As a result, protective coatings are generally used in conjunction with cathodically protected structures to reduce current requirements. A well-coated, buried pipeline (i.e., epoxy primer and polyethylene wrap) may require only a fraction of the amperage per square foot as a bare pipe buried nearby. Coatings on such buried structures which are cathodically protected must also be resistant to the alkaline environment produced as a by-product of the system.

The basic practical differences between galvanic and impressed current cathodic systems are shown in Table 2-3.

Inhibitors

Inhibitors are chemicals added in small amounts, either continuously or intermittently, to acids, cooling tower water, steam, or other environments to achieve a less corrosive condition. They may reduce corrosion by forming a very thin film on the metal substrate, by causing a passive layer to form on the surface, or by removing the aggressive constituents from the environment. The best known corrosion inhibitors are those used in antifreeze and coolant liquids for engine cooling systems.

Table 2-3

Galvanic vs. Impressed Current Cathodic Systems

Galvanic (Sacrificial Anodes)

Requires no external power supply

Low maintenance and installation costs

Interference to other structures is usually nonexistent

Usually does not require additional rights-of-way

Adjust output as structure potential varies

Severely limited current output

Useful only in low-resistivity electrolytes

Impressed Current

Requires external power supply

Requires higher installation and maintenance costs

Can cause interference problems

Usually results in a monthly power bill

Protects larger, more complex structures

Voltage and current can be easily varied

Suitable for high-resistivity electrolytes

3 COATING TYPES AND CHARACTERISTICS

A coating is composed of three basic compounds: vehicle (or binder), pigments, and solvents. There are numerous types of coatings, with the properties of each type dependent on the vehicle employed. Each type has certain characteristics which can be referred to as principal advantages and disadvantages, and the vehicles can be either inorganic or organic.

The inorganic coatings (i.e., zinc silicates) may be thought of as a pigment suspended in a vehicle. Here the pigment consists of metallic zinc dust, and the vehicle is a blend of water-soluble silicates.

Organic coatings are also composed of pigments suspended in a vehicle. However, the vehicle is primarily a resinous binder dissolved in solvents, together with a small quantity of driers, plasticizers, and stabilizers as required. As the paint dries, these vehicles change from a liquid to a solid by one or more of the following mechanisms: (1) evaporation of solvents, (2) oxidation (of a drying oil), (3) polymerization through the application of heat or catalyst, or (4) a combination of reactive components. With the exception of inorganic zinc coatings, all of the paints on Corps of Engineers projects are organic (e.g. vinyl, coal tar epoxy, alkyd).

The pigments contribute such properties as inhibition of the metal surface (e.g., red lead and zinc chromate), reinforcement of the film, stabilization against deterioration by sunlight, controlled chalking, color, hardness, and a variety of other characteristics. Clear coatings such as varnishes, lacquers, and shellac are not pigmented.

Solvents, generally referred to as thinners or volatile vehicle, are added to paint for various reasons. The primary reason is to permit easier application, or to make a solution of resin which will dry to form a film. Since the solvent is volatile, it disappears completely from the dry paint film in time.

Drying Oil (Oleoresinous Paints)

All paints of this classification have in common the use of an unsaturated or "drying oil" in the binder. The drying oil may have synthetic resins added in solution in the vehicle as with oil base paints, or the oil may be chemically pre-reacted with the resins during "cooking" of the varnish, as with alkyds, phenolic varnishes, and epoxy esters.

Paints of this class dry initially by solvent evaporation, followed by curing of the paint film through the addition of oxygen from the air at points of unsaturation in the drying oil. Because of the unsaturated oil in the binder, drying oil paints are not recommended for immersion service. Drying oil paints offer very little resistance to attack by acids and alkalies.

Oil Base Paints

Paints of this classification consist of drying oils only, or blends of oils with natural or synthetic resins. Oil base films dry initially by solvent evaporation, followed by the slower addition of oxygen from the air at points of unsaturation in the oil. Metallic driers are added to speed the drying time by accelerating the addition of oxygen at these

points of unsaturation in the oil. The drying time is a slow process and, therefore, these materials should be permitted to dry for 2 days between coats.

Oil base paints exhibit very good weathering properties, but are limited to atmospheric exposure under mildly humid or corrosive conditions in the absence of chemical, alkali, and acid fumes. Immersion service is not usually recommended. Oil base paints possess the ability to adhere to steel which has only been hand-tool or partially cleaned. This accounts for their widespread use as primers, where it is not possible to remove all rust and mill scale.

Alkyd Paints

Most alkyd resins for paints are made by formulating resins which are created by reacting certain polybasic acids with polyhydric alcohols. These resins are reacted together with varying quantities of drying oils, which impart flexibility to the resin. Alkyds cure by reacting with atmospheric oxygen.

The greater the oil content in the resin, the more flexible the coating will be; however, it also follows that the greater the oil content, the more the film will resemble an oil base paint. In general, the various oil modified alkyds are referred to as short, medium, or long oil alkyds. This "oil length" is expressed as the number of gallons of oil added to 100 pounds of resin:

Short Oil	5-15 gallons per 100 pounds of resin
Medium Oil	16-30 gallons per 100 pounds of resin
Long Oil	>30 gallons per 100 pounds of resin

Alkyds dry faster than oil based paints, with the drying time dependent on the amount of oil incorporated during formulation. Alkyds with shorter oil lengths will have quicker drying times. However, by virtue of the lower percentage of oil, they will also exhibit less ability to wet the steel substrate and consequently require a higher degree of surface preparation. They also yield a harder, less flexible film than alkyds with longer oil lengths.

Alkyds are widely used in industrial plants and for other nonimmersion mild atmospheric exposures. They are not recommended for immersion service.

Vinyl

Vinyl Butyral Wash Primers

Polyvinyl acetals are the products of the condensation reaction between polyvinyl alcohol and aldehydes. The aldehydes of commercial importance for this use are formaldehyde, acetaldehyde, and butyraldehyde. The reaction can be controlled to yield acetals having various ratios of acetate, hydroxyl, and acetal groups. In general, solubility decreases while viscosity and strength increase with increasing degree of acetalization. The resins are usually supplied as powders which may be compounded with plasticizers and other resins to produce tough, elastic, water-insoluble coatings.

Polyvinyl butyral, the best known of these materials, is known for its wide use as the clear, tough interlayer in safety glass. However, it also performs very well in the coatings field and has proved particularly useful as a base for wash primers and metal

conditioners. As made commercially, polyvinyl butyral resins contain a considerable percentage of hydroxyl groups (about 7 percent) which impart a hydrophilic character to the resin and contribute to its excellent specific adhesion to nonporous surfaces such as metal.

The most important coatings application of polyvinyl butyral has been as the base for corrosion-inhibiting metal primers (wash primers) using chromate pigments for corrosion inhibition, and phosphoric acid to achieve metal conditioning and cross-linking of the coating. Such wash primers have excellent adhesion to metal substrates and to virtually any type of topcoat lacquer or paint (except a few types of vinyl coatings such as Corps formulas V-102, V-103, V-106, or V-766). Excellent all-vinyl-base coating systems for severe marine applications employ a polyvinyl butyral wash primer as the first coat applied to the metal (see Table 3-1).

Vinyl Chloride/Vinyl Acetate Copolymers

Polyvinyl chloride is a tough, transparent, thermo-plastic resin having a high inherent strength and excellent chemical resistance. Its properties stem in part from its crystalline nature. It is highly resistant to strong acids and alkalis, water, alcohols, aliphatic hydrocarbons, fats; and oils--but it is swelled by aromatic hydrocarbons. It is soluble in only a few special types of solvent, chiefly unsaturated ketones (mesityl oxide and isophorone) and alicyclic (cyclohexanone and tetrahydrofuran--THF) compounds. It is soluble also in nitrobenzene and in dimethyl formamide. Because of this very limited solubility in organic solvents, and because it is degraded by heat and by ultraviolet light unless properly stabilized, polyvinyl chloride by itself is not widely used in solvent-type coatings.

For solution coating applications, therefore, the polyvinyl chloride is copolymerized with vinyl acetate to yield a polyvinyl chloride vinyl acetate copolymer, the vinyl chloride constituting from 85 to 97 percent of the copolymer. Solution or suspension polymerization methods are usually employed. The vinyl chloride vinyl acetate copolymers retain much of the toughness and chemical resistance of polyvinyl chloride while gaining the greater flexibility and solubility of polyvinyl acetate. The copolymers are easily formulated into solution-type coating materials for air-drying applications. Like the parent polyvinyl chloride, the copolymers must be stabilized against the deteriorating effects of heat and ultraviolet light. Plasticizers, pigments, and fillers are incorporated as required for particular coatings applications. Polyvinyl chloride-acetate copolymers are soluble in ketones, esters, ethers, and chlorinated hydrocarbons. Aromatic hydrocarbons such as toluene and xylene are well-tolerated diluents and are nearly always part of the composite solvent formulation. In addition to the availability in a range of chloride-to-acetate ratios and a variety of molecular weights, vinyl chloride-acetate resins may be interpolymerized with a small proportion (about 1 percent) of maleic acid to impart improved adhesion of air-drying coatings to metal surfaces such as blast-cleaned steel.

Most unmodified vinyl chloride-acetate copolymers are poorly compatible with other resins. However, when modified by incorporating hydroxyl groups, the copolymer becomes compatible with various alkyd, phenolic, amino, and other resins.

Vinyl chloride-acetate copolymer coatings are odorless, tasteless, and nontoxic (unless rendered otherwise by modifying ingredients). The coatings are tough and flexible, resistant to water and chemicals, nonflammable, abrasion resistant, and weather resistant.

Table 3-1

**Adhesion Characteristics of Paints Made With
Copolymer and Vinyl Butyral Resins**

Civil Works/ Designation & Description	Examples of Coatings Based on This Resin	Paint Made With This Resin	
		<u>Will Adhere To</u>	<u>Will Not Adhere To</u>
Vinyl resin No. 1 (vinyl butyral type)	DOD-P-15328D pretreatment	Bare steel and other metals	Civil Works uses this resin only in pretreatments for bare metal surf.
Vinyl resin No. 2 (partially hydrolyzed vinyl chloride - vinyl acetate copoly- mer; contains hydroxyl groups in the molecular structure)	MIL-P-15929C & MIL-P-15930B	Itself, DOD-P- 15328D pre- treatment or to coatings made with resin No. 3 or 4	Bare steel
Vinyl resin No. 3 (straight (un- modified) vinyl chloride - vinyl acetate copolymer)	V-102 & V-103	Itself, or to paints made with resin No. 2 or 4	Bare steel nor to DOD-P-15328D
Vinyl resin No. 4 (vinyl chlor- ide - vinyl acetate copoly- mer, containing 1% interpolymer- ized maleic acid)	V-766 V-106	Itself, to bare steel, or to coatings made with resin No. 2 or 3	DOD-P-15328D pretreatment

The Corps of Engineers uses four types of vinyl resins for different applications (see Table 3-1).

1. A vinyl butyral wash primer based on the DOD-P-15328D specification. This wash primer is used over clean bare steel as a pretreatment/adhesion promoter.

2. Hydroxyl modified vinyl chloride/vinyl acetate copolymer coatings based on MIL-P-15929C and MIL-P-15930B. This hydroxyl modified paint will not adhere to bare steel and must be used over some other coating (i.e., itself, pretreatment such as DOD-P-15328D above or to another coating, such as Types 3 and 4 following).

3. Unmodified vinyl chloride/vinyl acetate copolymer paints such as Corps formulas V-102 and V-103. These materials will not adhere to a bare steel surface or a surface treated with a pretreatment such as No. 1 above. These materials will, however, adhere to themselves or to coatings made from Nos. 2 or 4.

4. Paints made from resins containing vinyl chloride/vinyl acetate interpolymerized with 1 percent maleic acid. These paints (for example, Corps formulas V-766 and V-106) are self-priming, in that they can be applied over bare steel. They do not adhere to pretreatments (such as No. 1 above) but can be applied over themselves, bare steel (as noted), or to coatings made from resins No. 2 and No. 3 above.

Catalyzed Epoxy Coatings

The resins in most epoxy coatings consist of a polymerization product of epichlorohydrin and bisphenol-A. The resins then undergo a crosslinking reaction at the time of application through the action of a basic catalyst or through the application of heat. Three types of catalyst are employed, each resulting in epoxy coatings with specific properties:

1. Polyamine catalysts produce hard, high-gloss, chemically resistant coatings for exterior atmospheric exposure. They are highly resistant to oil spillage, but are not recommended for immersion service.

2. Amine adduct catalysts are polyamines partially reacted with an insufficient amount of epoxy resin.

3. Polyamide catalysts are polyamines reacted with unsaturated fatty acids. These coatings are equal to amine-cured epoxies in atmospheric exposure, and are sufficiently superior in resistance to chemicals and water to be suitable for water immersion service. The Corps of Engineers coal tar epoxy formulas C-200, C-200A, and MIL-P-24441 "Paint Epoxy-Polyamide" are coatings of this type.

While the epoxy coatings have excellent atmospheric exposure resistance as noted above, one disadvantage is that they will chalk upon exposure to sunlight. If the chalking is objectionable, they are often topcoated with a urethane.

The word "epoxy" in industrial protective painting has become synonymous with good acid resistance as well as resistance to polar and nonpolar solvents. However, there are several basic types of epoxy coatings in current use, and each type differs considerably in its properties, resistance, and preferred usages. Fortunately, none of these epoxy types are bad coatings; each is good in its own proper usage. They are not equivalents, however, as some have implied. The current amide epoxies have reasonably

good resistance to acidic exposure and organic solvents. While this resistance is inferior to that of the straight amines, the amide epoxies have greater resistance to moisture than either the adduct or straight amine catalyzed epoxies. Application of the amide epoxies is less exacting than the straight amines or even adducts.

The amide epoxy is made by copolymerizing a polyamide resin with an epoxy resin in approximately equal quantities to produce a highly crosslinked film of two dissimilar materials. A polyamide resin alone is not an epoxy resin; its properties and its resistance are its own and not those of an epoxy resin. The copolymerization of the amide with an epoxy serves to combine the moisture resistance of the amide with the chemical resistance of the epoxy. As such, these materials, while not chemically resistant as an amine epoxy, contain an improved degree of moisture resistance which makes them good candidates for immersion service.

Coal Tar Epoxy

Coal tar epoxies make use of naturally occurring coal tar pitches which have been refined and are by-products of the coking industry. These pitches are typically combined with polyamide resins and accelerators which, upon mixing with liquid-type epoxy resins, polymerize to form a coal tar epoxy-polyamide paint. The presence of the epoxy polyamide provides the chemical and moisture resistance characteristics of such materials, while the coal tar pitch enhances their resistance to water and chemicals. In addition, coal tar pitches are relatively inexpensive and serve as a filler.

The Corps of Engineers uses coal tar epoxy formulas as its coatings C-200 and C-200a. Coal tar epoxies, by virtue of their hard, abrasion-resistant finish, provide heavy-duty protection and a significant degree of water, chemical, and solvent resistance. Epoxy resins adhere well to steel or concrete substrates.

Extending epoxy resin with economical water-resistant coal tar produces a high-solids coating which has performed well for many years on piping, gates, and a variety of other immersion locations. It can generally be brush, roller, or spray applied with or without a primer, and two coats provide a thickness of about 20 mils. The chemical curing mechanism imposes rigid requirements for thorough mixing and adherence to application and curing times and temperatures. Coal tar epoxy coatings, when cured, are very slick and solvent-resistant; consequently, they have intercoat adhesion problems if the time-to-recoat limitations of 24 to 72 hours are not rigidly observed. Topcoats of coal tar epoxy applied after that time cannot be expected to yield optimum intercoat adhesion. If the recoat maximum times cannot be observed, many specifiers provide that the surfaces must be sweep blasted to provide a "tooth" before topcoating, or wiped with some strong solvent. CW-09940 recommends the use of N, N-Dimethyl Formamide solvent or Bitumastic 2CB solvent from Koppers Company, Inc. If such softeners are used, the next coat of material must be applied within a period of 15 minutes minimum to 3 hours maximum.

In addition to intercoat adhesion concerns, another drawback of coal tar epoxy coatings is that they "blush" when applied or cured during periods of high humidity, or if a condensate forms on the coated steel during curing. This leaves a streaky, muddy brown appearance that is not visually pleasing, even though it has no harmful effect on the coating system unless it is to be topcoated. If topcoating is to be done, one of the treatments outlined above must be performed. Coal tar epoxy coatings lose gloss and become dull in prolonged sunlight exposure.

Bituminous Coatings (Cold Applied)

The coal tar pitches are fully "cured," and consequently dry solely by solvent evaporation. The bituminous pitches are dissolved in a suitable solvent, usually naphtha. One typical formulation, MIL-C-18480, used by the Corps of Engineers as a cold-applied coating, is a highly thixotropic, filled coal tar mastic. This thixotropic type of coating should be thinned only mechanically, never with solvents. This material is applied in a relatively thick film (20 to 40 mils), and has been modified with various fillers. These materials are highly impermeable to moisture and are highly resistant to water deterioration. They also show very good resistance to petroleum oils, weak acids, alkalis, and salts. They are, however, not resistant to hydrocarbon solvents, vegetable oils, and sunlight. Areas in which these materials are exposed to sunlight should be coated with an emulsified bituminous coating compound with a coal tar base. This emulsion will serve as a sunlight screen for the coal tar coating and forestall the occurrence of alligatoring. The principal use is for the protection of buried or submerged steel and/or concrete.

Zinc-Rich Coatings

Zinc-rich coatings are distinguished by having 75 to 95 percent by weight of zinc dust in the dried film. These highly loaded zinc-rich materials should not be confused with coatings containing lesser amounts of zinc dust in the dried film.

Inorganic zinc-rich coatings cure to a hard film which can serve as a single protective coat. This film protects steel by acting as a sacrificial anode, corroding in place of the steel (Figure 3-1). Upon exposure, insoluble zinc salts form and act as a barrier to moisture, further reducing corrosion. If the film is damaged, the zinc surrounding the damaged area protects that area by self-sacrificing; therefore, zinc coatings exhibit "self-healing" properties. As the coating dries by solvent evaporation during its initial phases, the zinc particles are packed closely together. This "packing" of the zinc particles must be sufficient to ensure electrical conductivity between the zinc particles and the clean steel substrate. Electrical conductivity through metal-to-metal contact is the root of the "galvanic" corrosion protection offered by inorganic zinc-rich coatings.

Inorganic zinc-riches have an alkyl or alkali silicate as their binder, and they are either post-cured or self-curing. The post-cured types use water solutions of alkali silicates as vehicles and require a mild acid curing solution to harden. The self-cured zinc-riches are more common and are either solvent or water based and do not require a curing solution.

Organic zinc-rich primers are based on chlorinated rubber, vinyl, epoxy, and other organic vehicles. As such, the organics combine the performance characteristics of their organic binder component with the corrosion protection offered by a zinc-rich coating. Organic zinc-riches are generally more flexible and tolerant of surface preparation than the inorganics, but have less heat resistance. Their actual temperature and solvent resistance vary widely depending on the vehicle type employed. Organics are much easier to topcoat than inorganics because of their organic vehicle. Because of their organic binder, they are also less reactive than the inorganics, and will normally dissipate more slowly in severe environments to give a much longer protection. In addition, these materials have excellent adhesion and resist undercutting. For these reasons, the organic zinc-rich coatings (vinyl zinc and epoxy zinc-rich) have been chosen as primers by the Corps of Engineers.

INHIBITION BY ZINC PRIMER

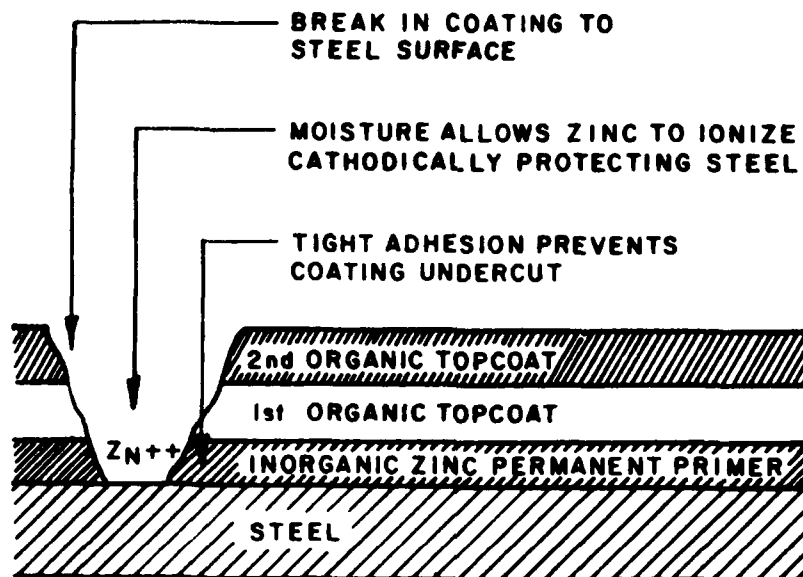


Figure 3-1. Inorganic zinc protection.

Due to the zinc pigments in the zinc-rich coatings, these materials are more difficult to apply than other coating material. It is very important when the zinc-rich coatings are being mixed that the zinc dust is slowly sifted into the liquid while mechanical agitation is being applied. During application, the mixing pot also should be mechanically agitated (Figure 3-2). Proper agitation during application is crucial to obtain a homogeneous film. With inadequate mechanical agitation, the heavy zinc pigment will settle to the bottom of the vessel, and will result in a pigment-rich applied film. This same settling can occur in either airless or conventional fluid hoses if spraying is interrupted for as little as 15 minutes. For that reason, the CWC Guide requires whipping the hose to redisperse the zinc or emptying the hose if spraying is interrupted for more than 1 hour. Without constant agitation and redispersion, a weaker, more porous coating will result. As the applied primer becomes resin-rich, the dried film will lose the properties of the zinc, offering little protection to the steel beneath. Thickness tolerances are also very critical with inorganics, as excessive coating thickness can result in "mudcracking." The mere presence of a zinc-rich primer also complicates topcoating. To avoid bubbling in inorganics as the air is displaced from the porous zinc surface, a tack coat, tie coat, mist coat, or over-thinned topcoat is often used.

Satisfactory application of the Corps of Engineers organic zinc-rich formulations depends on the application of a full wet spray coat. In this way, the coating film will be able to flow out, thereby wetting all surfaces and absorbing and wetting out any dry spray particles. (Pinholing is a common concern in vinyl coatings (including vinyl zincs) and is discussed in Chapter 7.)

Chlorinated Rubber Paints

The resin for these paints is obtained by reacting natural rubber with chlorine. The result is a hard, brittle resin that must be plasticized to make an elastic paint film. Stabilizers are also added to prevent deterioration by ultraviolet light from sunlight exposure for exterior service. Chlorinated rubber paint films dry solely by solvent evaporation, and exhibit very good adhesion to wood or concrete surfaces. Rust-inhibiting primers must be employed when chlorinated rubber paints are applied to steel surfaces. Chlorinated rubber paints have excellent chemical resistance and are also very resistant to water penetration and alkalis. The materials are often used for painting the interiors of potable water tanks and such immersion areas as swimming pools. Because of the strong solvents employed, chlorinated rubber paints should not be applied in combination with other types of coating to avoid compatibility problems. Chlorinated rubber coatings have low moisture vapor and oxygen transmission properties.

Table 3-2 outlines the principal advantages and disadvantages of frequently used industrial coatings.

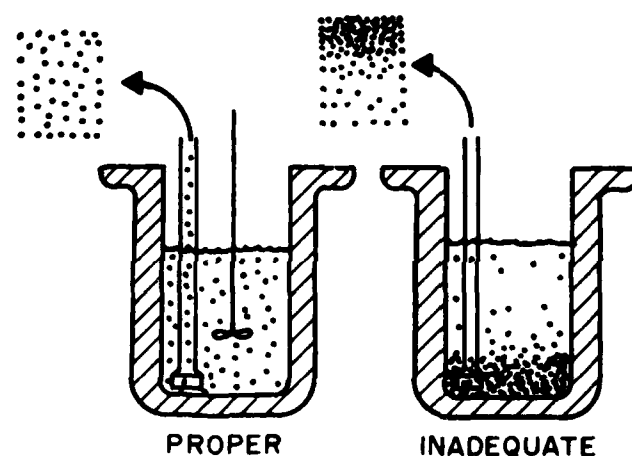


Figure 3-2. Agitation of zinc-rich coatings.

Table 3-2

**Principal Advantages/Disadvantages
of Frequently Used Industrial Coatings**

Generic Type and Curing Mechanism	Principal Advantages	Principal Disadvantages
1. Drying oils oxidation	<ul style="list-style-type: none"> *Very good application properties *Very good exterior durability *Outstanding wetting and penetration qualities *Excellent flexibility *Good film build per coat *Relatively inexpensive 	<ul style="list-style-type: none"> *Slow drying *Soft films-low abrasion resistance *Poor water resistance (non-immersion) *Fair exterior gloss retention *Poor chemical and solvent resistance
2. Alkyds oxidation	<ul style="list-style-type: none"> *Excellent exterior durability *Low cost *Excellent flexibility *Excellent adhesion to most surfaces *Easy to apply *Very good gloss retention *Good film build per coat 	<ul style="list-style-type: none"> *Poor chemical and solvent resistance *Fair water resistance (nonimmersion) *Poor heat resistance (typical sustained dry heat max. 200°F)
3. Vinyls evaporation	<ul style="list-style-type: none"> *Rapid drying and recoating *Excellent chemical resistance *Excellent water resistance (immersion) *Excellent durability *Very good gloss retention 	<ul style="list-style-type: none"> *Poor solvent resistance *Poor heat resistance (typical sustained dry heat max. 150°F) *Low film build per coat *Requires blast-cleaned surface
4. Chlorinated rubbers evaporation	<ul style="list-style-type: none"> *Rapid drying and recoating *Excellent chemical resistance *Excellent water resistance (immersion) *Excellent durability *Very good gloss retention 	<ul style="list-style-type: none"> *Poor solvent resistance *Poor heat resistance (typical sustained dry heat max. 150°F) *Blast-cleaned surface desirable
5. Epoxies polymerization	<ul style="list-style-type: none"> *Excellent chemical and solvent resistance *Excellent water resistance *Poor gloss retention *Hard, slick film *Excellent adhesion *Excellent abrasion resistance 	<ul style="list-style-type: none"> *Two package coating - limited pot life *Curing temperature must be above 50°F *Very good exterior durability *Film chalks and yellows on aging *Sandblasted surface desirable *Fair acid resistance *Intercoat adhesion *Impact resistance
6. Inorganic zinc polymerization	<ul style="list-style-type: none"> *Offers one coat protection under many service conditions *Excellent exterior durability *Excellent heat resistance to 700°F *Hydrocarbon insoluble *Provides "galvanic" protection properties *Provides "permanent" primer capability when used in conjunction with proper top-coats and/or maintenance practices *Self-curing *Selected ability to accelerate cure-depending on type used 	<ul style="list-style-type: none"> *High cost *Requires excellent surface preparation - approaching near white metal blast *Spray application only-skilled applicators required for successful job *Not suitable for acidic or caustic service unless properly topcoated *Requires careful selection of tie coats and top coats for service involved *Selected temperature and humidity effects-depending on type used

Table 3-2 (Cont'd)

<u>Generic Type and Curing Mechanism</u>	<u>Principal Advantages</u>	<u>Principal Disadvantages</u>
7. Organic zinc polymerization or evaporation	<ul style="list-style-type: none"> *Offer one coat protection under many service conditions *Excellent exterior durability *Provide "permanent" primer capability when used in conjunction with proper top-coats and/or maintenance practices *Require slightly less rigorous degree of surface preparation compared to inorganic zincs *Spray application preferred, but can be brush or roller applied *More forgiving during application 	<ul style="list-style-type: none"> *Topcoating problems (pinholding is common) *Lesser heat resistance depending on binder. Typical sustained dry heat max. 200°F *Generally solvent soluble depending on binder *Not suitable for acidic or caustic service unless properly topcoated *Requires careful selection of intermediate and topcoats for service involved *Coating film is softer, more flexible, and more susceptible to abrasion damage

4 SURFACE PREPARATION

Importance of Surface Preparation

Cleanliness is essential in preparing a surface to receive protective coatings. Paint applied over rust, dirt, or oil will bond poorly (or not at all) to the substrate, and early paint failure will usually result. A clean surface is free from contaminants such as rust, flash rust, dirt and dust, salts, oil and grease, dead paint, and mill scale. A brief discussion of each of these contaminants follows.

RUST cannot be penetrated by most paints, with the exception of the oil-based products. Painting over rust also creates an uneven coating, exposing metal to further corrosion.

FLASH RUST is a light layer of rust which forms on the cleaned steel soon after exposure to the air, particularly in moist or humid environments.

DIRT and DUST particles or spent abrasive interfere with the adhesion of the coating to the substrate and prevent the application of a smooth, uniform film of paint. Debris embedded in the film can also serve to wick moisture and corrosive elements through the film to the substrate.

SALTS of various chemicals accelerate the rate at which corrosion will occur. Salts trapped beneath the paint film can cause blistering in immersion service. Salts are likely to be trapped in pits and crevices, and particular attention must be given to cleaning these areas.

OIL and GREASE prevent good paint adhesion and must be completely removed. Welding smoke and inspection markings also leave an oily residue and must therefore be completely removed.

DEAD PAINT that is loose, cracked, or flaking will ultimately lift from the surface, resulting in cracking and peeling of the newly applied coating.

MILL SCALE is a crust (oxide) which forms on the surface of the steel as it is hot-rolled. It has a bluish, somewhat shiny appearance which may be hard to see on new or partially blast-cleaned steel. While difficult to remove, modern, high-performance coatings require the surface to be completely free of mill scale. Also, since the steel is anodic to the mill scale, once the scale is cracked, the underlying steel will corrode when exposed to moisture and oxygen. The Steel Structures Painting Council's definition of the various grades of surface cleanliness, in most cases, requires the complete removal of mill scale.

Other areas of the surface need to be addressed prior to the actual cleaning. Coating will generally not properly cover all surfaces of weld spatter. Weld spatter may also become dislodged in service, exposing the unprotected substrate. Sharp edges cause paint to draw thin because of surface tension effects, and should be eliminated by grinding (Figure 4-1). Inside corners provide a collection site for excess paint and/or abrasive, and should be filled. Crevices and pits should be filled with weld metal, if necessary, and smoothed. Some pits, because of their sharp, angular edges, will require extensive welding and grinding prior to surface preparation. Other pits, because they consist of smooth, even depressions, need only to be cleaned for coating.

In addition, for maintenance painting, the thick layers of stiff, old paint should be removed and glossy painted surfaces must be roughened. Nonferrous surfaces also frequently require some type of pretreatment. In the case of aluminum or galvanizing, degreasing and the application of a wash primer are often employed to provide proper adhesion.

In addition to cleanliness, the surface must be roughened to provide for a mechanical bond of the paint to the substrate. This roughening is termed anchor pattern, profile, or "tooth," and is essentially a pattern of peaks and valleys on the steel surface. This pattern is obtained by abrasive blasting and must be carefully controlled according to the coating system being applied. If the peaks are too high, they will stick out above the coating, causing pinpoint rusting (Figure 4-2). A good coating work procedure will

PAINT BEHAVIOR OVER SURFACE IRREGULARITIES		
IRREGULARITY	PROBLEM	CORRECTION
Sharp Corners & Edges	Insufficient Thickness	Grind To 1/4" Min. Radius
Inside Corners	Cracked Or Spongy Coating	Fillet Weld & Grind To 1/2" Minimum Radius
Projections	Insufficient Thickness Cracked Or Spongy	Grind Flush
Pits & Crevices	Cracks Or Sponge Entrapped Air	Fill With Weld Metal & Grind Flush

Figure 4-1. Sharp edges.

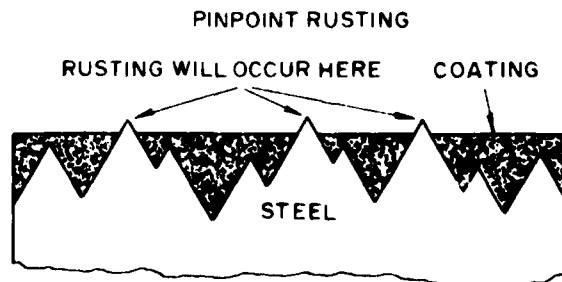


Figure 4 2. Pinpoint rust due to excessive profile height.

specify how high the peaks must be for that job. This height is measured in mils, which is a thousandth of an inch (0.001 in.), and is controlled by the type, size, and hardness of the abrasive used. A rule of thumb for surface profile is that it should be approximately one-third of the required coating system thickness (up to a coating thickness of 12 mils).

Methods of Surface Preparation

A variety of surface preparation methods are available:

- Solvent or chemical wash
- Steam cleaning
- Hand tool cleaning
- Power tool cleaning
- Water blasting
- Abrasive blast cleaning.

Each of these is discussed below.

Solvent Cleaning

Solvent cleaning (SSPC-SP1) removes oil and grease, and is usually used in conjunction with or prior to the mechanical methods of preparation. Because of rapid contamination, fresh solvent must be used continuously, and the rags or cloths must be turned and/or replaced frequently; otherwise the grease and oil will only be spread across the surface rather than removed. The final wash should be made with clean solvent. The organic solvents used should not come in contact with the eyes or skin, or be used near sparks or open flames.

Disadvantages of solvent cleaning are that it has no effect on rust or mill scale, it is very slow and labor-intensive, and the materials are rapidly used up and need constant replacement. In addition, many of the solvents used are highly flammable and should not be inhaled due to their toxicity. Natural or mechanical exhaust ventilation to dilute the concentration of vapors in an enclosed working space should be employed during the entire work period.

Steam Cleaning

Steam cleaning uses high temperature/high velocity wet steam to remove heavy soil, oil, or grease. It does not remove rust or mill scale, nor does it etch or roughen the surface. Commercial detergents can be added to the steam to improve cleaning. On steel, it is sometimes followed by spot blast cleaning or wire brushing on areas exhibiting coating failure or rusting.

Hand Tool Cleaning

Hand tool cleaning (SSPC-SP2) is used only for removing loosely adhering paint, rust, or mill scale. It is slow and thus used mostly for spot cleaning. Hand tools include scrapers, wire brushes, abrasive pads, chisels, knives, and chipping hammers.

The disadvantages of using these tools, in addition to the speed, are that they will not remove tightly adherent contaminants (i.e., dirt trapped in crevices, or oil or grease), and they may raise burrs or dent the surface, actually causing damage. In addition, of course, these tools will generally not provide a surface profile.

Power Tool Cleaning

Power tool cleaning (SSPC-SP3) is faster than hand tool cleaning; removes loose paint, rust, and scale; and is good for the preparation of welded surfaces. It is also good for feathering old paint which has been lifted by rust. It provides a duplication of hand tools in power driven equipment (electric or pneumatic), such as sanders, wire brushes, grinders, clippers, scalers, needle guns (Figure 4-3), and rotary descalers (Figures 4-4 and 4-5). Generally, power tool cleaning is only suitable for small areas, because it is

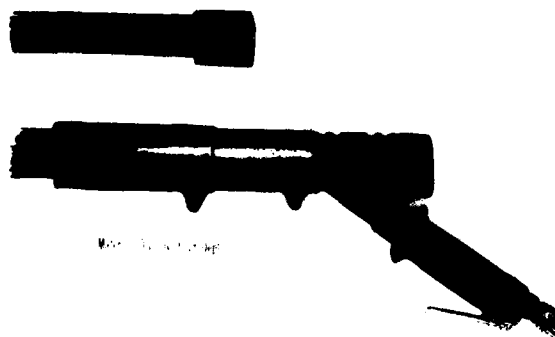


Figure 4-3. Needle gun.

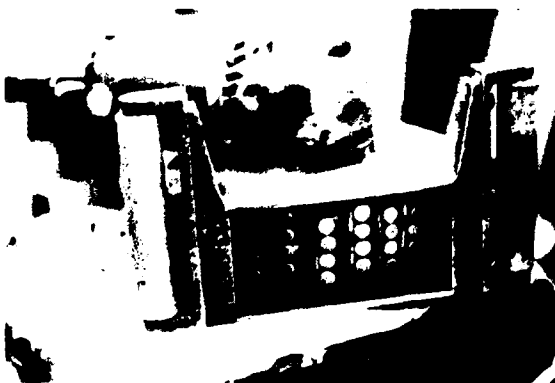


Figure 4-4. Rotopeen tool.



Figure 4-5. Clean-N-Strip (3M).

relatively slow. Power tools do not leave as much residue or produce as much dust as abrasive blasting, and are frequently used where blasting dust could damage sensitive surroundings. However, they may polish the surface if they are used at too high a speed or kept in one spot too long.

Water Blasting

Water blast cleaning (sometimes called hydroblasting) may be high or low pressure, hot or cold, and with or without a detergent, depending upon the type of cleaning desired (Figure 4-6). This process removes loose, flaky rust and mill scale. It has gained wide acceptance where abrasive blast cleaning, dust, and contamination present a hazard to either personnel or machinery (Figure 4-7).

Low pressure (less than 2,000 psi) washing is effective in removing dirt, mildew, and chalk from the coating surface, and is generally safe on concrete/masonry surfaces. Low pressure water blast units use the same components as high-pressure water blasting. Low pressure cleaning is referred to as power washing, and should be recognized as such.

For cleaning steel, water pressures as high as 10,000 psi or more and volumes commonly in the 8 to 10 gallon per minute range are used to remove loose, flaky rust, paint, or mill scale.

Water alone does not etch a metal surface or remove tight paint, rust, or mill scale. Therefore, abrasives may be injected into the water stream to remove tightly adhering materials, for faster cleaning, or for producing a profile. Any type of abrasive commonly used with air blast cleaning can be used in water blast cleaning; sand is the most common. Because the abrasive is normally not dried, screened, and recycled, less expensive abrasives are commonly selected in this application. Abrasive is injected into the system after water is pressurized by means of a suction head to prevent pump damage. Injecting abrasive into water eliminates dust that normally accompanies dry use of such abrasives.

Flash rusting is a concern when using these methods. Flash rust is a light rust layer that forms on steel after cleaning, particularly after water or wet abrasive blasting, or in humid marine environments. To avoid flash rusting, rust inhibitors such as sodium and/or

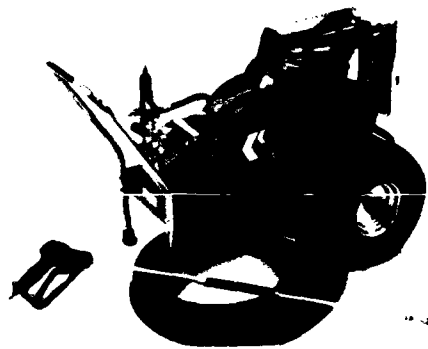


Figure 4-6. Water blast equipment.

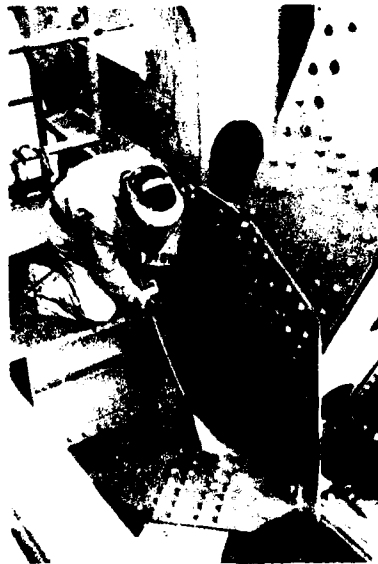


Figure 4-7. Water blasting during use on structural steel.

potassium dichromate or phosphate are often used during or after water blasting; they may retard rusting for up to 7 days. The drawback of these corrosion inhibitors is that the solutions, upon drying, leave salts that can cause adhesion problems for protective coatings. The prime consideration, therefore, should be to determine if the protective coating is compatible with the inhibitor that was used.

To assess the adhesion effect of the inhibiting solutions commonly employed, it is normally recommended that a section of the structure be blast-cleaned and inhibited, followed by the application of the coating system in question. After a suitable dry/cure time, the surface should be examined and the adhesion of the coating assessed prior to the wholesale use of an inhibitor on a structure.

Abrasive Blast Cleaning

Abrasive blast cleaning is the preferred surface preparation method for paints and coatings which require an anchor pattern and a high degree of cleanliness. Blast cleaning is the only method which can completely remove intact mill scale and give an even roughness with a controlled anchor pattern. Abrasive blasting is the propelling, or "shooting" of sand or other types of small, hard particles at a surface (Figure 4-8). In nozzle blasting, the force which propels the abrasive is compressed air. Traveling at a speed of 200 to 400 miles per hour, the abrasive strikes the surface, breaking and loosening the rust or scale.

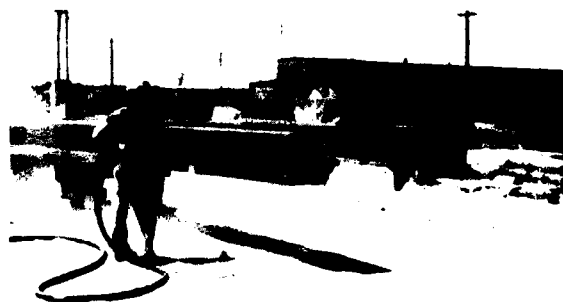


Figure 4-8. Abrasive blasting.

The cleaning principle is the same in centrifugal wheel blasting. In this case, the spinning of large paddle wheels creates the force to throw the abrasive at the surface (Figure 4-9). This method is usually confined to shop use, with the units approximately the size of a large trailer, although smaller one-man units have been developed for preparing floors or ship hulls. In contrast with open blast cleaning, the abrasives used are recyclable steel grit or shot.

Vacuum blasting is another option for "dust-free" blast cleaning. With this technique, the blast nozzle is surrounded by a brush and a vacuum is pulled. The spent abrasive and removed paint, rust, and debris are contained by the brush, removed by the vacuum, and transported to a separator. The debris and fine particles are removed, and the abrasive returned for reuse. This method is very slow, as the blast pattern is approximately 1 in. in diameter. However, for small areas or where dust cannot be

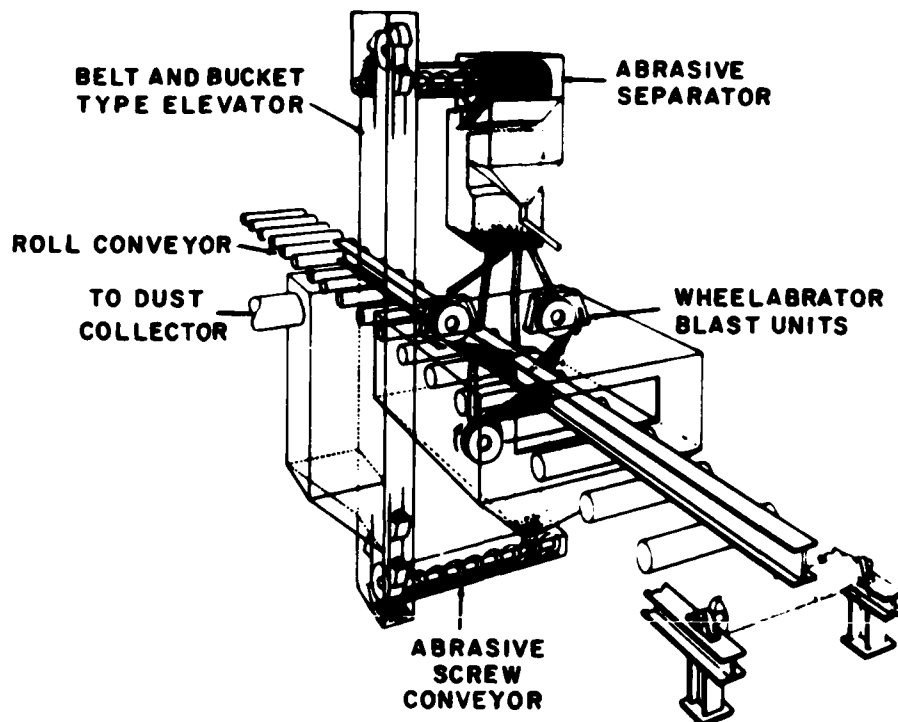


Figure 4-9. Centrifugal blasting machine.

tolerated, it may be the best alternative. The brush or housing surrounding the nozzle is available in a variety of shapes to form to pipe, corners, and other irregular surfaces.

Blast cleaning can result in a variety of degrees of surface cleaning, ranging from superficial surface cleaning to the complete removal of all mill scale, rust, or debris. The grades of cleaning are identified as Brush-Off (SSPC-SP7), Commercial (SSPC-SP6), Near-White (SSPC-SPI0), and White (SSPC-SP5). The specific definitions are provided later in this section. Blasting is ideally suited for high production work because it rapidly cleans large areas. In spite of its efficiency and good results, some problems still occur, such as accumulation of used abrasives in low-lying areas, and the attendant difficulty in removing them. Airborne dust and abrasive can interfere with machinery, the work of the persons nearby, and can contaminate adjacent locations. Airborne dust can be a hostile environment for the blast operator, and an air-fed hood must be worn while operating the air blast cleaning equipment. In addition, open nozzle blast abrasives are expensive and are usually not recycled in the field.

Blast Cleaning Equipment

Open nozzle blasting equipment has seven basic components (Figure 4-10): air compressor, air hose, moisture and oil separator, blasting machine, blast hose, nozzle, and safety.

Air Compressor

The air compressor is the source of energy for the blasting job. The constant supply of a high volume of high-pressure air stream hour after hour is the most critical part of blast operations.

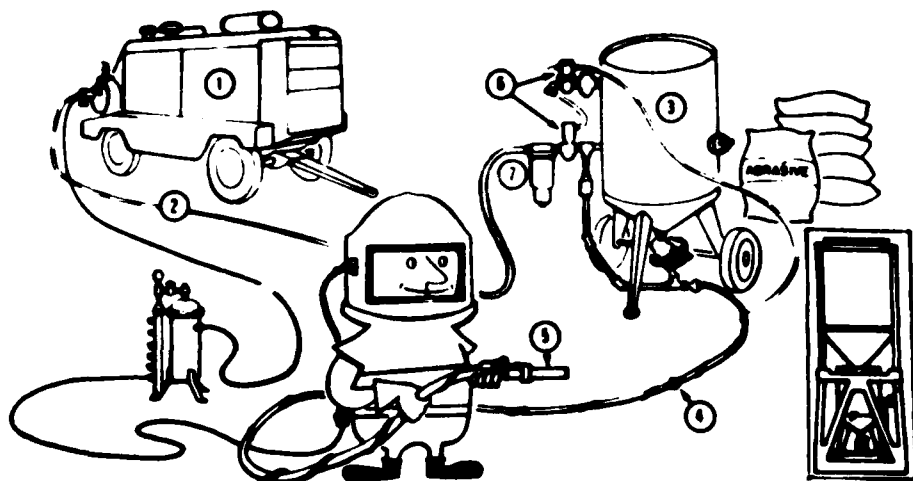


Figure 4-10. Basic components of open nozzle blast-cleaning apparatus.

Work is done in direct proportion to the volume and pressure of air at the nozzle, as shown in Table 4-1. The larger the compressor, the larger the nozzle it can operate. The larger the nozzle at the proper pressure, the faster the job can be completed.

Table 4-2 shows the air and sand consumption of sandblast nozzles at various pressures. It shows lower air consumption than older tables because it represents air carrying abrasive, not just free air through an orifice. The H.P. figure represents the horsepower electric motor required to produce the indicated CFM.

The crucial importance of nozzle diameter, pressure, and air volume can be seen as follows: at 90 psi, a 1/4-in. nozzle will consume 74 CFM of air, while a 5/16-in. nozzle will consume 126 CFM of air. Since work is done in direct proportion to the volume and pressure of air at the nozzle, a 5/16-in. nozzle can generate almost 170 percent of the cleaning accomplished with a 1/4-in. nozzle, if enough air is available to maintain the nozzle pressure at 90 psi.

If nozzle pressure with the 5/16-in. nozzle should drop to 70 psi because of inadequate air supply, air consumption drops to 101 CFM from 126 CFM. This 20 psi drop in nozzle pressure causes a loss of 25 CFM or 19.8 percent ($25 : 126 \times 100\%$) in the cleaning rate. To repeat, work will be done in direct proportion to the amount of air and pressure passing through the nozzle. The effect, then, of raising nozzle pressure for a 5/16-in. diameter nozzle from 70 to 90 psi will be to raise the rate of cleaning 20 percent.

Air Hose

The air hose connects the compressor to the blast pot. For efficient blasting, the air hose should be as large an inside diameter (ID) as practical in order to reduce friction and avoid air pressure loss (many people recommend a minimum 1-1/4-in. ID air hose). This air hose cannot be too large, but if the hose size is too small for the volume of air

Table 4-1

Effect of Nozzle Pressure on Cleaning Rate

Nozzle Pressure, psi	Cleaning Rate, %
100	100 (Standard for comparison)
90	82 approx.
80	78 approx.
70	60
60	50

Table 4-2

Air and Sand Consumption of Sandblast Nozzles at Various Pressures

Nozzle Diameter (Inches)	50	60	70	80	90	100	
1/8 . . .	11.3	13.2	15.1	17.	18.50	20.25	Air
1/8 . . .	67.	77.	88.	101.	112.	123.	Sand
1/8 . . .	1.61	2.07	2.55	3.09	3.55	4.19	H.P.
3/16 . . .	26.	30.	33.	38.	41.	45.	Air
3/16 . . .	150.	171.	196.	216.	238.	264.	Sand
3/16 . . .	3.56	4.59	5.51	6.92	7.87	9.32	H.P.
1/4 . . .	47.	54.	61.	68.	74.	81.	Air
1/4 . . .	268.	312.	354.	408.	448.	494.	Sand
1/4 . . .	6.44	8.26	10.19	12.37	14.2	16.77	H.P.
5/16 . . .	77.	89.	101.	113.	126.	137.	Air
5/16 . . .	468.	534.	604.	672.	740.	812.	Sand
5/16 . . .	10.55	13.62	16.87	20.56	24.19	28.36	H.P.
3/8 . . .	108.	126.	143.	161.	173.	196.	Air
3/8 . . .	668.	764.	864.	960.	1052.	1152.	Sand
3/8 . . .	14.8	19.3	23.9	29.3	33.2	40.6	H.P.
7/16 . . .	147.	170.	194.	217.	240.	254.	Air
7/16 . . .	896.	1032.	1176.	1312.	1448.	1584.	Sand
7/16 . . .	20.1	26.0	32.4	39.5	46.1	52.6	H.P.
1/2 . . .	195.	224.	252.	280.	309.	338.	Air
1/2 . . .	1160.	1336.	1512.	1680.	1856.	2024.	Sand
1/2 . . .	26.7	34.3	42.1	51.0	59.3	70.0	H.P.

Source: Blast Off--Abrasive Blasting Cost Saving Techniques (Cleeco Industries, 1976)

passing through it, frictional losses will cause a loss of pressure and poor blasting efficiency. A 15 percent production loss can result from a 10 lb drop in pressure. The air hose should also be as short as practical to reduce leakage, and contain as few couplings as possible. Since many Corps of Engineers projects use two or more blasters from a sand pot, the air hose must be adequately sized so that proper nozzle pressures can be maintained. Air hoses as large as 3 or 4 in. have been used.

Moisture and Oil Separators

The large consumption of compressed air in an abrasive blast operation introduces the problem of moisture (especially in high humidity areas) and oil mists from the lubricating oils in compressors. This is especially true in portable compressors. To combat this, an adequately sized oil/moisture separator should be installed at the blast machine (the most distant point from the compressor) to eliminate 95 percent of the contaminants. Separators are usually of the cyclone type with expansion chambers and small micron filters. They require solvent cleaning to remove oil and routine replacement of filters.

Blast Pot

The blast machine or sandpot is a pressurized container which holds the abrasives (Figure 4-11). A valve at the bottom measures and controls the amount of abrasive fed into the blast hose. This metering valve is often called the "carburetor valve."

A typical gravity-fed blast pot consists of (1) an air hose, (2) a moisture/oil separator, (3) an inlet and exhaust valve, (4) a filling head, (5) a metering valve, and (6) the hose pot coupling. Efficient abrasive blast operations require the right size pot for the job, which enables very few refill stops, and the releasing of an even flow of abrasive with the air stream. Proper abrasive flow is controlled by the metering valve.

While manually operated air inlet and outlet valves are used on many blast pots, CW-09940 requires that they be replaced by a so-called "Deadman Control." These

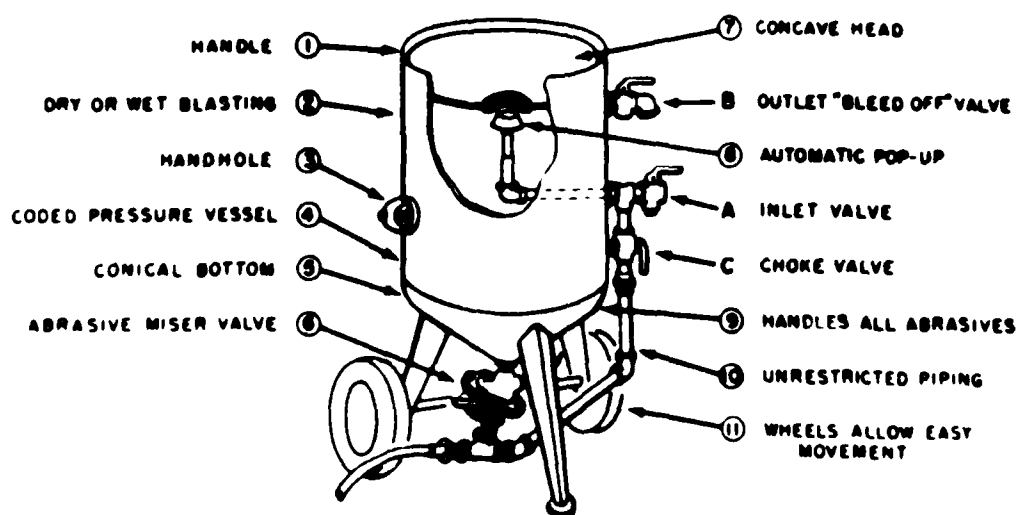


Figure 4-11. Blast pot - gravity-fed.

remote-controlled "dead man" valves have been designed to fit any existing sandblast machine. They eliminate the need of the pot tender and provide 100 percent safety to the person doing the blasting. To start the machine, the blaster presses down on the Deadman Control Valve, allowing the air inlet valve to open and the air outlet valve to close, at which time blasting commences. To stop the operation, the Deadman Control Valve is released, which permits the closing of the air inlet valve, shutting off any incoming air from the compressor to the machine and instantly opening the bleed-off or sandblast machine's depressurizing valve. This instantly shuts down the operation. These valves can be installed on any sandblast machine regardless of manufacture.

In addition to safety considerations, these valves offer manpower savings. It is possible to completely eliminate the pot tender on small jobs, and on jobs where multiple machines are being run, it is possible to operate from four to six sandblast machines with one pot tender responsible only for keeping the units filled with abrasive.

Blast Hose

The blast hose connects the blast pot and nozzle and carries both air and abrasive. It is treated to prevent electrical shock by the installation of a grounding line. Sturdily constructed multiple-ply hose with a minimum of 1-1/4-in. ID is required in most work. On Corps of Engineers projects, blast hoses of 1-1/2-in. ID are commonly used. A short length of lighter, more flexible hose with a 1 or 1-1/4-in. ID is sometimes joined in at the end. These sections, called "whips," are easier to handle and are effective for work in areas with many angles, pipes, and stiffeners. The use of whips will, however, reduce the pressure at the nozzle and cancel the advantage gained by a large-diameter blast hose; thus their use should be discouraged except where necessary. The rule of thumb in open nozzle abrasive blast cleaning is the use of bigger and shorter hoses. Maximum blast efficiency requires that the length of hose between the blast pot and the nozzle be kept as short and straight as possible to avoid wear.

Only externally fitted quick couplings should be used. No coupling or pipe fitting inside the hose should be used, because it will: (1) reduce the ID of the hose, thereby reducing air volume at the nozzle, and (2) cause air turbulence inside the hose where the air and abrasive strike the leading edge of the internal coupling. This turbulence will further reduce air pressure and volume at the nozzle. The abrasive action on the internal coupling will cause very heavy wear at that point.

The quick couplings for sandblast hose are all externally fitted and held in place by screws penetrating into the wall of the hose. The screws should not penetrate through the tube, as air leaks can occur around these screws. The quick couplings have universal jaws, allowing one to couple 1-1/2-in. hose to 1-1/4-in. or to 1-in. They all have replaceable gaskets so that a perfect air seal is obtained. These quick couplings create a rubber tunnel from the sandblast machine to the nozzle.

With quick couplings, all that is required is the removal of the safety tie wire and a turn of the wrist to remove a section. Quick couplings secured with tie wires provide an extra margin of safety and, by enabling the quick removal of excess hose sections, save considerably in hose purchases over a period of time. The use of safety fastenings on the couplings is mandatory on Corps projects.

Quick couplings are available in either brass or aluminum. Brass gives considerably greater life; however, many contractors prefer the aluminum variety because of their lightweight quality where hoses are being raised high into the air to clean objects such as dam gates.

Quick couplings should be equipped with sled-like runners so that if they are being dragged over irregular surfaces such as structural steel, they will not hang up.

Nozzle holders are available that are attached to the hose in the same manner as the quick couplings.

The end of the hose should be square cut for proper fit in the coupling.

Quick couplings are available to fit up to 1-1/2-in. ID sandblast hose.

Blast Nozzle

The nozzle is a major element in the blasting operation. Nozzle sizes are identified by the diameter of the orifice. Diameters are measured in sixteenths of an inch. A 3/16-in. diameter orifice is designated No. 3; 5/16-in. a No. 5, and so forth. Nozzles are commonly available up to 1/2-in. (No. 8) in diameter. Surface cleaning is done in direct proportion to the volume of air pushed through the nozzle at high pressure. For example, if 100 sq ft/hr can be attained with 1/4-in. nozzle, 400 sq ft/hr can be attained with a 1/2-in. nozzle. It is apparent, then, that when the nozzle size doubles, the cleaning rate increases by a factor of 4. However, the nozzle can be too large for the air volume. In that case, air will escape, causing the pressure and production to drop. Therefore, nozzle size should be as large as permitted by the air supply to maintain a 90 to 100 psi air pressure at the nozzle.

Nozzles come in an assortment of lengths, sizes of opening, lining materials, and shapes. Because of the heavy demands of blasting work, it is recommended that the nozzles generally have the following characteristics. Nozzles should use the Venturi design, they should be as long as practical, use a Tungsten carbide or Norbide lining, and have as large an orifice size as is possible with a given compressor. For difficult to reach places, nozzles also come in shapes such that they can propel abrasives around corners, in a 360 degree arc, or even backwards.

Venturi Design. This refers to the tapered shape of the lining of a Venturi nozzle (Figure 4-12). It has the advantage of increasing the abrasive speed to 450 mph, and creating a larger, more even blast pattern. Production cleaning rates can be increased by as much as 30 to 50 percent by use of a Venturi nozzle over a conventional nozzle with a straight bore.

IMPROVED VENTURI DESIGN

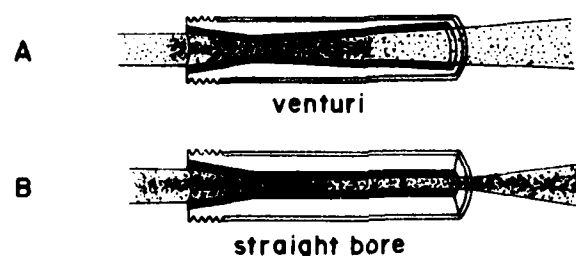


Figure 4-12. Straight versus Venturi nozzle design.

Nozzle Length. Hard-to-clean surfaces require as large a nozzle as practical for the work area. Nozzles from 5 to 8 in. long will more easily remove tightly adhered deposits of mill scale. They also produce faster cleaning rates. Shorter nozzles, 3 in. or less, may have to be used behind beams or in other small or inaccessible areas.

Nozzle Linings. As the abrasive material flows past the nozzle opening, the lining wears away, increasing the bore of the nozzle. The size of the opening, called the orifice, reduces cleaning effectiveness as it is worn away. Nozzle liners should be replaced when wear increases the opening 50 percent of the original diameter size. Tungsten carbide and Norbide liners, when properly handled, have a service life of 300 and 750 to 1,000 hours, respectively.

Proper Care of Nozzle. Nozzles are expensive so proper care is crucial. Careless handling can damage these tools. Tungsten carbide or Norbide nozzle lining materials are brittle, and using the nozzle as a hammer or dropping it can crack the lining.

Safety

Major safety and health hazards faced by blasters include:

1. Respiratory problems
2. Toxic effects
3. Skin disease
4. Burns
5. Eye injury
6. Hearing loss
7. Fire and explosion
8. Equipment accidents.

While these potential hazards exist on all work sites, there are also many safety measures which can be taken to avoid accidents and illness. Understanding the function and capabilities of protective devices is the responsibility of the Corps of Engineers inspection personnel. These devices must be used correctly to ensure safety on the job site.

Respiratory Problems

One of the most common hazards facing operators is respiratory disease due to dust or toxic fumes. Respirators provide good protection during all surface preparation operations.

During abrasive blast cleaning, air-fed respirators and hoods must be used, especially in enclosed spaces where there is a great amount of dust.

When abrasive blasting is being used on Corps projects, the dangers of dust inhalation make the use of an air-feed hood mandatory. These hoods must be of a positive pressure type certified by the National Institute for Occupational Safety and Health (NIOSH) or the Mining Enforcement Safety Administration (MESA). Breathing air must meet the requirements of the Compressed Gas Association Pamphlet G-7.1, Specification Grade D. A breathing air type of compressor must be used on Corps projects as the source of air supply. If an oil-lubricated compressor is used to provide breathing air for respirators, it must be equipped with a high temperature or carbon monoxide alarm or both. If only a high-temperature alarm is used, the compressors must be frequently checked.

Respirators. Air-fed respirators are recommended when solvent cleaning. To be effective, all respirators must fit properly and be carefully maintained. A respirator maintenance program for the use and maintenance of respirators must be established on all Corps projects. The program must include instruction in the proper use and maintenance of respirators and their limitations. It must provide the user an opportunity to handle the respirator, have it fitted properly, test its facepiece-to-face seal, wear it in normal air for a long familiarity period, and finally wear it in a test atmosphere. When the user must wear corrective spectacles or corrective lenses as part of the facepiece, they must be worn so as to provide good vision, comfort, and a gas-tight facepiece-to-face seal. The maintenance program must provide for the inspection for defects (including a leak check), cleaning and disinfecting, repair, and storage.

In addition, the respirator user's medical status must be determined by a physician and reviewed periodically (for instance, annually). Persons must not be assigned to tasks requiring the use of respirators unless they have been determined physically able to perform the work and use the equipment and have no illness which may be aggravated by intended cleaning or painting operations.

In short, the program must be effective in instructing personnel in the proper use and maintenance of respirators, including:

1. Keeping them in top working condition.
2. Cleaning and checking them after each use and replacing filters or cartridges as often as necessary.
3. Storing them in a clean, dry container in a place that is free from exposure to solvents or other harsh cleaning compounds.

Ventilation. Adequate ventilation must also be provided during all surface preparation activities. The work area must be properly ventilated to avoid respiratory damage. Workers other than blasters working in areas where unsafe concentrations of abrasive materials and dusts are present must wear proper clothing, safety goggles, and filter-type dust respirators. The dust-type respirators must be kept clean, fit well, and contain lenses of unbreakable glass or plastic and allow adequate peripheral as well as straight-ahead vision. Persons whose vision requires the use of corrective lenses shall use goggles which will fit over the lenses. Filter-type respirators must be NIOSH or MESA certified for dusts not significantly more toxic than lead.

Toxic Effects

Toxic or poisonous substances and fumes can enter the body in several ways. They can be inhaled, swallowed, and absorbed through the skin.

Damage to the nervous and digestive systems may not be noticed for many years. Long-range effects may appear as lung diseases such as silicosis and certain forms of cancer.

Other toxic effects are immediate. Symptoms such as headaches, coughing, rashes, and dizziness appear soon after contact with a poisonous substance.

Proper choice and consistent use of respirators and protective creams and clothing shield the body from these harmful substances. Adequate ventilation in the work area also reduces exposure to problem substances.

Skin Disease

Skin irritation is a common problem among blasters. Skin rashes, also called dermatitis, can result from direct contact with an irritating chemical or certain metallic dusts. In chemical cleaning, such as the pretreatment of metals and concrete with phosphoric or other similar acids, burns and dermatitis can result from contact with these materials.

Skin irritations can be prevented by using protective skin creams and protective clothing, including heavy-duty gloves. Abrasive blast cleaning also demands the use of protective clothing to protect all parts of the body from irritating dusts and abrasive bounce-back.

Burns

An operator can receive burns from heat, electricity, or direct contact with chemicals. The metal parts of a steam gun must be insulated to protect against heat burns.

Chemical burns are caused by direct skin contact with harsh, harmful chemicals, as in solvent cleaning. Butyl rubber gloves should always be worn in this operation. Other protective clothing, such as goggles, coveralls, and boots, can prevent solvent splashing from burning other areas of the body.

Steam cleaning may cause burns from the steam under very high pressure. To guard against these hazards, wear a face shield, gloves, and a protective rain suit.

Ground all electrical power cleaning tools to prevent sparking and electrical burns. The equipment should be inspected for safe operating conditions. Tools with faulty plugs or broken wires may short-circuit, causing electrical burns and/or fire.

Eye Injury

Eye injuries are probably one of the most common forms of injury reported by workers. Potential eye injuries include:

1. Impact (eyes struck by or against objects)
2. Chemical splash
3. Eye scratches and abrasions.

Eye protection is an important precaution that must be taken during any surface preparation operation where there is a danger of flying particles or chemicals which can blind or cause other serious injuries. Safety goggles must be worn on Corps projects. The Corps also requires that eye lavage and deluge showers be provided in shop settings. *If eyes are contaminated, copious quantities of water must be used to irrigate them for at least 15 minutes. Of course, medical attention should also be sought.*

Hoods provide a greater degree of protection from dust and flying particles, shielding the eyes, face, neck, and ears. In blasting, they protect the eyes and head from abrasive ricochet.

Hearing Loss

Hearing loss can occur from exposure to high noise levels for long periods of time.

Chipping and blasting are two surface preparation operations which produce excessive noise. Ear plugs should be worn in all areas where operations with excessive and continuous noise levels are taking place.

Fire and Explosion

Fire and explosions are potential safety hazards faced by all surface preparation operators. Hand and power tools must be nonsparking and explosion-proof, especially in the presence of combustible vapors. Some abrasives can cause sparks when the particles strike the surface. If work is being done in a confined area, it must be proven gas-free by use of a calibrated explosimeter or organic vapor analyzer. Sparks flying in an area containing flammable materials or combustible vapors present a potential explosion or fire hazard.

In the use of chemical cleaning agents or volatile solvents, adequate ventilation is ALWAYS called for.

OSHA requirements state that "suitable fire extinguishing equipment shall be immediately available in the work area and shall be maintained (ready) for instant use."

Equipment Accidents

Safe use of all surface preparation equipment will reduce accidents. All equipment should be inspected for good working condition.

In accordance with OSHA rules, faulty hand and power tools such as cracked grinders and wheels or broken wires can seriously injure an operator. All power equipment should be held correctly and operated at the speed recommended by the manufacturer. Where necessary, tools should be effectively grounded.

The pressure of the tank used in abrasive blast cleaning must be carefully watched to make sure it does not exceed the maximum allowable pressure for the pot. "Sandpots" fall under the category of unfired pressure vessels and must meet certain standards.

During solvent cleaning, care must be taken not to splash the chemicals. Machinery parts will be destroyed and scaffolding ropes could be weakened, resulting in serious accidents.

Electric shock can occur in certain situations. In blast cleaning, the nozzle should be grounded so it will not discharge high static electricity and shock the blaster. The shock itself is not lethal but falling off a scaffold may be.

In water blasting, electric shock can be conducted through wet surfaces. All electrical operations should be shut down when water blasting is in process.

Use all surface preparation equipment correctly and only for the intended purpose. "Horseplay" on the job should never take place. Pointing a blast nozzle at a person, even in fun, can be a deadly mistake. The powerful force of a blast stream is similar to a continuous-action shotgun which will cut ropes and other rigging, so it should never even come near scaffolding. Never point powerful equipment at anything other than the surface to be cleaned.

The use of safety belts and lines is an obvious precaution in any number of blasting situations above or below ground; such use is often required by law. This is true when a blaster is working in any situation where the operator must be removed quickly in case of an emergency.

Where rigging of any kind--scaffolding, swing stages, bosun's chairs, slings--is used, safety belts and lines should have substantial guard rails. The force in a blasting pass tends to push the operator backward. Most blasters are aware of this force and stand in a braced position to lessen its impact on them. Safety measures include back rails, stabilizing lines, and sure footing.

Should an accident occur, every person should know where emergency phone numbers are posted and where emergency equipment and supplies are located. At least one employee should be qualified to give first aid, if there is no separate first aid room or health attendant.

Blasters and other operators should be aware of the dangers possible in their jobs. However, safe use of equipment and other precautions will prevent accidents. Thorough safety training is essential for efficient and productive workers.

Blast Cleaning Efficiency Checklist

For efficient blasting, the several rules should be followed:

1. Place the compressor near the blasting job, as near as possible to the blasting pot. Position it so that the wind will blow spent abrasive away from the compressor, assuring a clean air intake.
2. Run a large air hose from the compressor to the blast pot. A large hose reduces frictional pressure losses in the line.
3. Care for the equipment. Allow the compressor to warm up for 10 to 15 minutes before starting to blast. Set the compressor at 120 lbs.
4. Keep the compressor clean. Fans, radiators, and filters should not be clogged with dirt, or they will overheat and overload the compressor.
5. Check the compressor output every six months. An "orifice gage" is available for this purpose.
6. Use external couplings when attaching hoses.
7. Keep hoses as short as possible to minimize pressure loss.
8. Avoid small sand blast hose. The inside diameter of the air blast hose should be three to four times the orifice of the nozzle. Use a 1 in. or 1-1/4 in. ID whip only in areas with many angles or stiffeners, when greater flexibility is an absolute must.
9. Run the hose in a straight line. Avoid 90 degree bends. If the hose must curve around an object, use a long, gentle curve. Consider safety as well as productivity. Sharp curves create rapid wear and could cause a blow-out.
10. Check for nozzle orifice wear.

Blast Cleaning Technique

For effective nozzle operation, the blaster must adjust the proper abrasive flow and maintain the proper angle of attack, and the proper distance between the nozzle and the surface. Experimentation with different angles and distances when starting a new job will determine what is most effective for the surface condition. Once the most efficient angle and distance are determined, the blaster should maintain them with each pass during the entire operation.

Air Abrasive Mix

The open air blast cleaning nozzle is adjusted to the proper balance of abrasive and air when the air stream from the nozzle is a slightly blue color (Figure 4-13). Experience is ultimately the best teacher, but many operators tend to use too much abrasive, which cuts down blasting speed, creates excessive dust, and increases clean-up costs. The mixture of air and abrasive is adjusted by the metering valve, or carburetor, of the air blast machine.



Figure 4-13. Open nozzle abrasive blast cleaning at work.

Angle of Attack

The angle of the nozzle to the surface ranges from 45 to 90 degrees (Figure 4-14). To remove rust and mill scale, 80 to 90 degrees to the surface is preferred. This angle is also suitable for dislodging contaminants from pitted surfaces. A slight downward angle also directs the dust away from the operator, making it easier to see. To peel old paint and layers of rust from the surface, force the blast under the crust of the coating or rust at a 45 to 70 degree angle.

Nozzle-to-Surface Distance

The closer the nozzle to the surface, the smaller the blast pattern (Figure 4-15). With a small pattern, the abrasives are concentrated in a smaller area, make impact at a

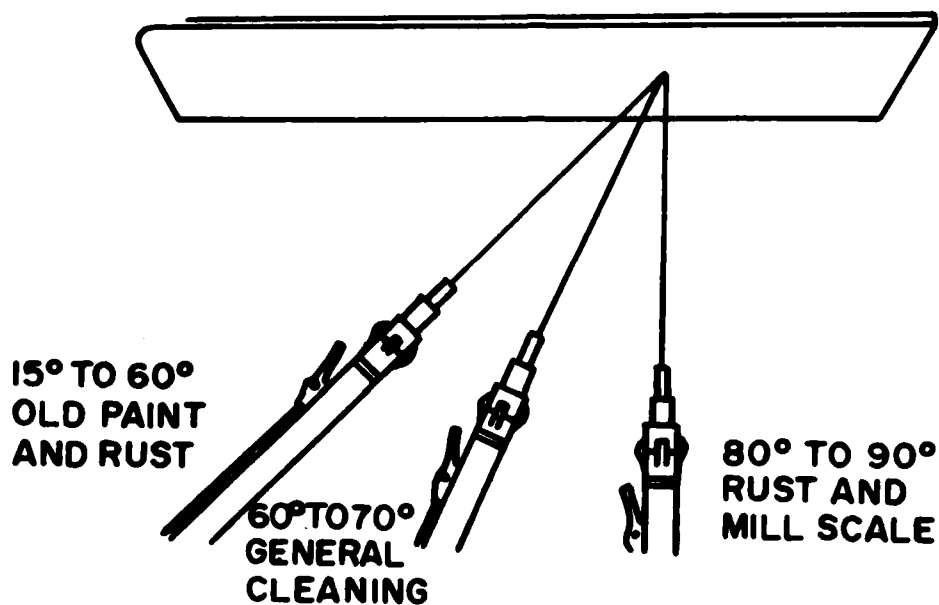


Figure 4-14. Angle of attack for various degrees of blast cleaning.

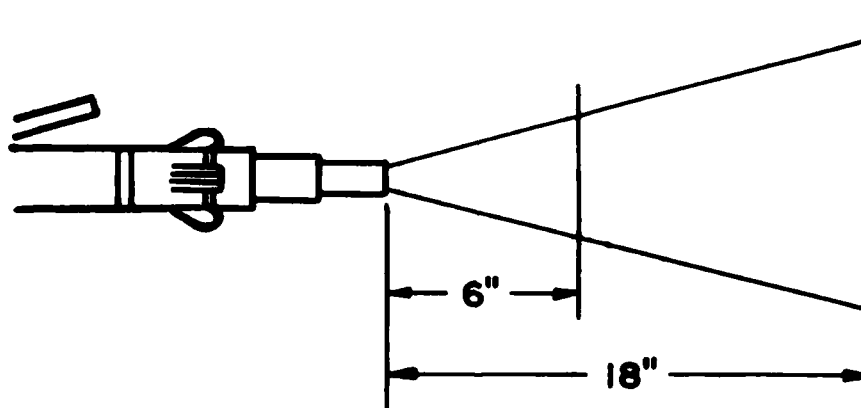


Figure 4-15. Nozzle-to-surface distance.

greater speed, and have more force. On a small area, the operator can blast more crust for the energy spent, but will cover less area in a given time. A distance of only 6 in. may be required to remove tight scale, whereas to remove old paint, an 18 in. nozzle-to-surface distance may be effective.

Each pass should be straight and at the same distance to produce work of a uniform quality (Figure 4-16). There should be no arcing or varying the distance from the work.

Size of Surface Area To Blast Clean at One Time

The size of the area to be blast cleaned at a given time should never be more than can be primed the same day. The operator should blast clean small sections and protect

those with primer immediately. One should not blast a large section and leave it exposed. In humid areas, rust bloom or flash rust can be seen on exposed surfaces within hours. The work in removing this before painting is an unnecessary expense. On flat surfaces of minimal complexity, the rule of thumb is that one spray painter can keep up with four blasters. On complex configurations which are heavily corroded, the rate of blast cleaning to painting will be dramatically different. The inspector should develop his/her own "rule of thumb" on a project-by-project basis by observing how long the relative blast and paint times actually are on various aspects of the work. For example, the outside skin plate of a dam gate may fall within the four blasters to one sprayer rule, whereas on the structural steel supports, one sprayer may be able to keep up with eight blasters.

Abrasives

Size and Hardness

The proper abrasive is the one that provides the necessary cleanliness and profile. The characteristics of such an abrasive related to performance include the following.

Size. A large abrasive particle will cut deeper than a smaller size of the same composition and shape, and thus provide a deeper surface profile. However, the greatest cleaning rate is achieved with the smaller abrasive due to a larger number of impacts per unit area. Abrasive particles larger than 16 to 18 mesh may gouge the metal surface and thus have a slow cleaning rate. Fine particles (80 mesh size or finer) cannot achieve the 1-1/2 to 2-1/2 mil profile usually desired for high performance coatings. Particles in the 40 to 50 mesh range are commonly used.

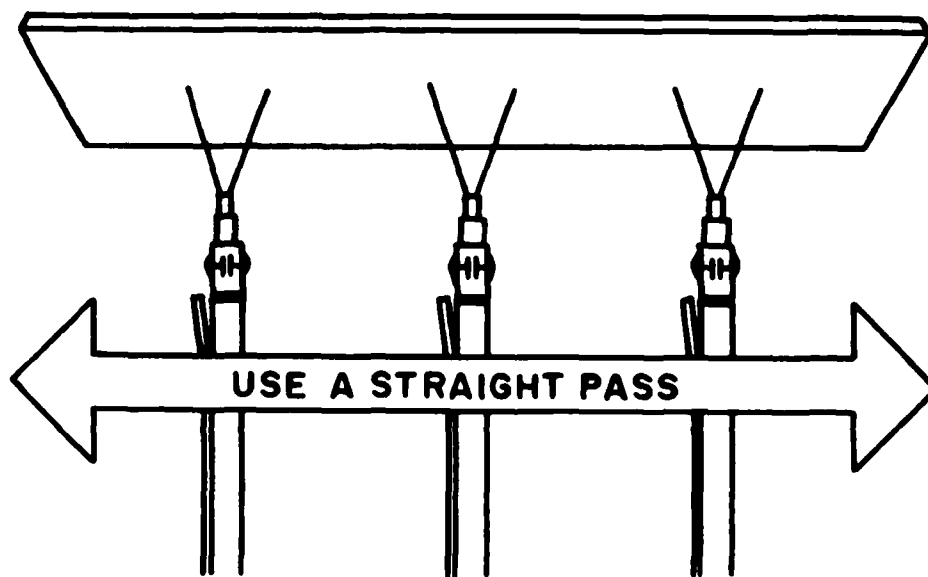


Figure 4-16. Straight pass of blast nozzle.

Hardness. Hard abrasives generally cut deeper and thus faster than softer or brittle abrasives. A hard but brittle abrasive will shatter on impact, reducing its cleaning power accordingly.

Abrasive Breakdown Characteristics

Abrasive grains striking the work surface at high speeds are themselves damaged. The way in which they fracture and/or change their shape and size is called their breakdown characteristics. This is particularly important when the abrasive is recycled or reused because it limits the amount of recycling possible without adversely affecting cleaning rates. A breakdown of more than 10 percent in one use results in a significant increase in dusting, requires extra cleaning of the surface for removal of breakdown deposits, and limits the number of times an abrasive can be reused.

Shape

The shape and size of abrasive grains determines the type of surface profile achieved by the blast cleaning. Steel shot, because it is round, peens the surface to give a wavy profile. Shot is therefore particularly effective at removing brittle deposits such as mill scale. Grit, on the other hand, is angular; blast cleaning with it produces a jagged finish which is generally preferred for coating adhesion. A wide variety of surface patterns is available from different grits. Use of sand and slag abrasives which are semi-angular results in a pattern somewhat between that of shot and grit (Figure 4-17).

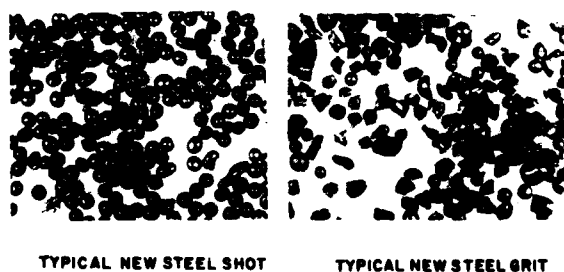


Figure 4-17. Abrasive shape.

The abrasive should be a neutral pH, i.e., between 6 and 8. It should not be washed with sea water or other contaminated water. Four abrasive materials are commonly used on a nonrecycled basis:

1. **Natural oxides.** Silica is the most widely used natural oxide because it is readily available, low in cost, and effective. The hazards of silica have been recently elucidated by both the EPA and OSHA, and the use of silica abrasive has been restricted in many areas. Another natural abrasive, Starblast, also a silica material, has received attention in recent years. It consists of a blend of coarse and fine staurolite sands mined from certain mineral deposits in Florida. It is characterized as efficient cutting and has less dusting and a lower breakdown rate than silica sand.

2. **Metallic abrasives.** Steel shot and grit abrasives are efficient, hard, and dust-free, but care must be taken in their storage to prevent rusting. While their initial cost

is higher, they may be recycled many times to make them cost-effective. A mixture of both shot and grit abrasives in blasting may combine the advantages of both. The impact of steel shot may cause small slivers, called hackles, to form on the surface of the steel. These hackles may be up to 6 mils high, and must be removed mechanically by sanding or grinding before coating to avoid pinpoint corrosion of the metal projecting through the coating.

3. Slag abrasives. Copper and nickel abrasives are a by-product of the ore smelting industry. These are fast cutting, but have a high breakdown rate, and are generally not recycled. These abrasives are the most likely to exhibit a pH on the acid side. Probably the best known of these materials is "Black Beauty."

4. Synthetic abrasives. Aluminum oxide and silicon carbide are non-metallic abrasives with cleaning properties similar to the metallics, without the problem of rusting. They are very hard, fast cutting, and low dusting, but quite costly and must be recycled for economical use.

Storage

Generally, abrasives should be kept in their original sealed containers until ready for use. They should be stored off the ground on wooden pallets and covered with a sheet of plastic if left outdoors. If bulk abrasive is used, it should be stored in a hopper or protective housing, not in a pile on the ground.

Quality Concerns During Blast Cleaning

Measuring Air Pressure at the Nozzle

The air pressure at the nozzle is measured using a hypodermic needle gage (Figure 4-18).

The needle gage is easy to use. It is inserted into the blast hose as near to the nozzle as possible. The needle must point in the direction of the blast abrasive flow. The measurement is made while the abrasive is flowing to give a true reading of the pressure of the air/abrasive mixture which exits the nozzle. Readings should be taken at the start of every shift.

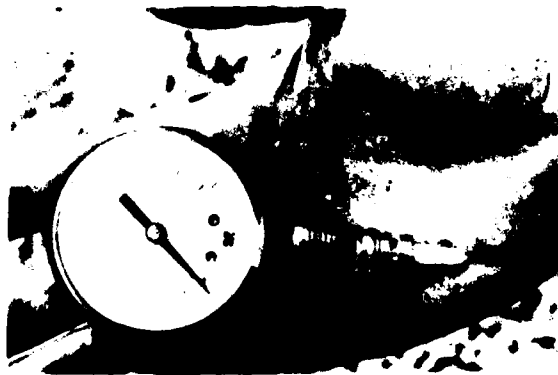


Figure 4-18. Hypodermic needle gage.

The needle gage reading indicates the pressure at the nozzle, where the work is actually being done. Reading the pressure gage on the compressor or on the blast pot tells the pressure at those points only. Due to friction losses, pressure drops through the pot, etc., the compressor gage might read 90 to 100 psi, but the nozzle pressure considerably less. Hypodermic needle gage readings of 90 to 100 psi are considered optimum. Lower readings reduce abrasive efficiency; greater readings do not increase efficiency but do lead to operator fatigue.

Quality of Air Supply

Air which carries dirt and oil defeats the purpose of blast cleaning. The air, as well as the abrasive, must be clean, dry, and oil free. Water in the blast stream can cause spot rusting on the steel. Water and oil separators on the compressor and blast pot will solve these problems, but they require regular attention.

Contamination of the air supply can be detected by a simple blotter test. A plain, white blotter is held 18 in. in front of an air outlet downstream of moisture and oil separators. The air should flow for one to two minutes. Stains on the blotter indicate a contamination of the air supply that requires corrective action.

Cleanliness of the Abrasive Material

The use of clean abrasive material will prevent surface contamination clogging of the blast pot or nozzle. Abrasives carrying oil or water will stain and spot-rust a steel surface. The cleanliness needed for paint to bond cannot be achieved if the surface is not clean.

To check the cleanliness of the abrasive, place a small amount of abrasive in a glass jar filled with water. Shake the jar: if an oil film appears on the surface of the water, the abrasive is not clean and should not be used. This test is of vital importance when the abrasive is recycled, as the abrasive will pick up oil from contaminated pieces and continually redeposit it.

Ambient Conditions

Because cleaned steel will rust quickly when exposed to moisture, it is generally agreed in the industry that final work in preparation for painting should not be performed if the relative humidity exceeds 90 percent or the surface temperature is less than 5° F above the dewpoint (the temperature at which moisture from the surrounding air will condense on a surface). If a surface is at or cooler than the dewpoint, moisture will form on the surface, resulting in rusting. The 5° F spread is a safety factor due to the variation in ambient conditions throughout the work area and instrument inaccuracies. While this rule is generally followed, it is not often possible on dam gate projects where leaking bulkheads may provide direct water sprays and undesirable ambient conditions. In these cases, economics may dictate that a "best effort" will prevail, and that the steel be coated and protected as best and quickly as possible. In normal circumstances, the ambient conditions and surface temperatures should be monitored every 4 hours during final surface preparation activities. More frequent monitoring may be desirable if conditions are changing or minimum/maximum conditions are being approached.

Standards of Cleanliness

The most frequently used standards for cleaning steel surfaces for the application of coatings are in the *Systems and Specifications, Steel Structures Painting Manual* published by the Steel Structures Painting Council (SSPC). Volume I is a source of information about good painting practices and Volume II is an excellent source of information about cleaning and coating systems and specifications.

Surface preparation can range from simple dry wiping and air blowdown to very thorough abrasive blast cleaning. Each results in different degrees of cleanliness and acceptance criteria. Although cleanliness is perhaps the single most important aspect in determining a coating's longevity, it is also the most subjective to inspect.

Both SSPC and NACE have established written specifications and standards for classifying degrees of cleanliness. Visual supplements are available from both organizations to depict the cleanliness for some of the methods. NACE has encapsulated plates prepared to the various degrees, while SSPC has adopted the Swedish Photographic Standards. Unfortunately, neither addresses the appearance of previously coated steel. Also, no standards will appear identical to the conditions in the field. Because of this, standards prepared at the jobsite are often the best approach. Prior to commencing the work, sections of the actual structure to be painted are prepared and agreement reached on the degree of cleaning obtained. The samples can then be sealed in plastic or coated with a clear urethane to serve as a visual reference for the remainder of the project.

The various types of cleaning and brief definitions follow:

Solvent Cleaning	SSPC-SP1	NACE - none
Hand Tool Cleaning	SSPC-SP2	NACE - none
Power Tool Cleaning	SSPC-SP3	NACE - none
White Metal Blast Cleaning	SSPC-SP5	NACE 1
Approaching White Metal Blast Cleaning	SSPC-none	NACE - none
Commercial Blast Cleaning	SSPC-SP6	NACE 3
Brush-Off Blast Cleaning	SSPC-SP7	NACE 4
Pickling	SSPC-SP8	NACE - none
Near-White Blast Cleaning	SSPC-SP10	NACE 2

Solvent Cleaning - SSPC-SP1. Solvent cleaning is used to remove oil, grease, dirt, soil, drawing compounds, and various other foreign matter by use of solvents, emulsions, cleaning compounds, or steam cleaning. Solvent cleaning does not remove rust or mill scale. Visual Standards -- none available.

Hand Tool Cleaning - SSPC-SP2. Hand tool cleaning is the method of removing loose rust and loose mill scale or any other loose contaminants from the surface by hand tools. It does not require the removal of intact rust or mill scale. Visual Standards -- SSPC-VIS I - BSt2, CSt2, DSt2.

Power Tool Cleaning - SSPC-SP3. This method provides for the removal of loose rust and loose mill scale (or any other loosely adherent contaminant) from the surface by power tools. Power tool cleaning does not require the removal of intact rust and/or mill scale. Visual Standards -SSPC-VIS I - BSt3, CSt3, DSt3.

White Metal Blast Cleaning - SSPC-SP5-71; NACE 1. White metal blast cleaning is used when a totally cleaned surface is required. This method of cleaning is defined as a blast-cleaned surface with a gray-white uniform metallic color. It shall be free of all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, stains, streaks, or any other foreign matter across 100 percent of every square inch. Visual Standards -- SSPC-VIS I - ASa3, BSa3, CSa3, DSa3; NACE 1.

Approaching White Metal Blast Cleaning. The Corps of Engineers has introduced a special grade of cleaning for surfaces subject to extended periods of immersion (or otherwise as required). This method requires that prior to blast cleaning, visible grease or oil should be removed by solvent cleaning per SSPC-SPI. After blast cleaning the surface of the structure, mentally divide the surface into squares approximately 6 in. on a side. Seventy-five percent of the squares shall be free of all rust, mill scale, or staining (e.g., White Metal). The remaining 25 percent are permitted to contain very slight shadows, stains, or discolorations resulting from very thin, adherent, sparsely scattered residues of mill scale or corrosion products. However, on surface irregularities such as edges, interior angles, welds, rivet lines, junctions of joining members, and pits, the White Metal grade of cleaning shall be strictly enforced.

Commercial Blast Cleaning - SSPC-SP6-71; NACE 3. A commercial blast-cleaned surface is defined as one in which all oil, grease, dirt, mill scale, rust, and old paint have been completely removed from the blast cleaned surface, except that slight streaks or discolorations caused by rust stain, mill scale oxides, or slight tight residues of paint or coating may remain. If the surface is pitted, slight residues of rust or paint may remain in the bottom of the pits. The slight discolorations mentioned above are limited to one-third of every square inch. Visual Standards -- SSPC-VIS I - BSa2, CSa2, DSa2; NACE 3.

Brush-Off Blast - SSPC-SP7-71; NACE 4. A brush-off blast is defined as one in which all oil, grease, dirt, rust scale, loose mill scale, and loose rust and loose paint or coatings are completely removed. Tight mill scale and tightly adherent rust and paint or coatings may remain as long as the entire surface has been exposed to the abrasive blasting. Visual Standards -- SSPC-VIS I - BSa1, CSa1, DSa1; NACE 4.

Pickling - SSPC-SP8. This method of surface preparation is defined as completely removing all mill scale, all rust, and all rust scale by chemical reaction, or by electrolysis, or by both. Visual Standards--none available.

Near-White Blast Cleaning - SSPC-SPI0-71; NACE 2. This degree of blast cleanliness is defined as one in which all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, or any other foreign matter have been completely removed from the surface. Permitted to remain are very light shadows, very slight streaks or discolorations caused by rust stain, mill scale oxides, or slight tight residues of paint or coating. Only 5 percent of every square inch may contain the slight discolorations mentioned above. Visual Standards -- SSPC-VIS I ASa2-1/2, BSa2-1/2, CSa2-1/2, DSa2-1/2; NACE 2.

In 1982, changes in the SSPC Surface Preparation Standards were made. For the blast cleaning specifications, these changes permitted the staining to remain across a percentage of the surface rather than restricted to every square inch. That is, a Near-White Blast was defined as one in which 95 percent of the surface area is equivalent to White Metal with the stains, shadows, streaks, and discolorations permitted across the remaining 5 percent, provided they were generally evenly dispersed.

The changes have been controversial, however, and it is expected that the square inch requirement will be reimposed soon.

Visual Standards

The Swedish Standards (SSPC-VIS I) are the most commonly used visual standards for evaluating the cleanliness of prepared surface. The use of these standards requires initially determining the rust grade of the uncleaned steel. These are graded Rust Grade A, B, C, and D, respectively.

Rust Grade A -- Adherent Mill Scale (tightly adherent mill scale with little rust)

Rust Grade B -- Rusting Mill Scale (rust initiated, mill scale flaking)

Rust Grade C -- Rusted (mill scale rusted or easily scraped away; little pitting visible)

Rust Grade D -- Pitted and Rusted (no mill scale and pitting visible).

Once the grade of rusting has been established, visual and written standards can be used to determine the level of blast cleaning for Groups A, B, C, and D. The appearance of the same levels of cleaning with different grades of steel may be quite different. Care should be taken not to confuse slight rust staining or dirt containing iron compounds with rust.

5 COATING APPLICATION

The newer, synthetic paints are particularly sensitive to poor application as compared to the older linseed oil and red lead alkyd formulations. Thus, great care must be exercised in using the application procedures recommended by the paint supplier. The following items should be considered when selecting a paint application method for a particular job: speed, ease of application, simplicity of equipment, safety, material conservation, portability, versatility, initial economics, and long-range economics.

Brush Versus Spray

In most large jobs, spray painting is the preferred application method. It can more efficiently provide a high, uniform film thickness and good appearance in one coat compared to a brush or roller application (Table 5-1). A good painter can apply paint by brush to about one thousand square feet of flat area in eight hours. The same painter could apply paint by roller to between two and four thousand square feet. However, when using conventional spray, productivity increases to four to eight thousand square feet, and with airless spray, eight to twelve thousand square feet per eight hour shift is possible. With airless spray equipment, an operator can cover eight times the area of brush application in the same amount of time. When spraying, it is sometimes necessary, however, to mask adjacent areas if they are to be protected from being coated.

Table 5-1
Application Rates by Method of Application

Characteristic	Brush	Roller	Spray
Speed	Fair	Good	Excellent
Ease of Application	Fair	Good	Poor
Simplicity of Equipment	Excellent	Excellent	Poor
Safety	Excellent	Excellent	Poor
Material Conservation	Excellent	Good	Poor-Good*
Portability	Excellent	Good	Poor
Versatility	Good	Fair	Excellent
Initial Economics	Excellent	Excellent	Poor
Long Range Economics	Fair	Fair	Excellent
Hiding Power	Good	Fair	Poor-Good*
Uniformity	Poor	Fair	Good

*Varies with Equipment and Operator.

Paint Storage

Proper paint storage will protect costly paint materials from premature deterioration and minimize fire hazard. The room or building specially designated for storing paint should be isolated from other work areas. It should be dry, well ventilated, and protected from direct sunlight, sparks, and open flames. Dampness can cause the can to

corrode and the paint to become contaminated. Temperature extremes must be avoided, with most paints ideally stored between 40°F and 100°F. Freezing can permanently compromise the performance of some coatings.

If it is necessary to take large quantities to a remote jobsite, the coating should not be exposed to the weather. Can labels should be kept intact before use and free of paint after opening, so that the contents can be readily identified. The can should not be opened before needed to avoid contamination. Also, air reacts with certain paints to reduce the paint shelf life. Once opened, a can should be used before another can is opened. Fresh paint should always be purchased rather than using old or reworked paint. The paint should never be allowed to exceed its shelf life (normally a year or so from the date of manufacture) before use unless retested.

Stock should be arranged so that the first paint received is the first paint used. Also, no more paint should be purchased than can be used within its shelf life.

Application Temperatures

Most paints should be applied at temperatures between 50°F and 90°F; painting below 45°F or above 95°F should be avoided for most systems. The best temperature range for conventional air spraying is 60 to 90°F. However, vinyls and chlorinated rubber coatings can be applied at temperatures as low as 35°F. The temperature of the material being applied should be at least as high as the surface to be coated, and never outside the recommended temperature range. For example, while hot spray is commonly used to increase the paint temperature prior to and during application, this warm paint should not be applied to a surface below the dewpoint. A relatively large, cold mass of steel will not be heated merely by the application of hot paint. Spray painting during windy conditions (in excess of 15 mph) can lead to paint droplets becoming airborne. These droplets can be carried long distances and deposited on inappropriate surfaces. In addition, strong air currents can exaggerate dry spray and overspray conditions by more quickly removing solvents from the coating, reducing its wet time.

Paint Viscosity

Three factors affect paint viscosity:

1. Solvent-to-solids ratio
2. Paint temperature
3. Mixing of thixotropic paints.

The solvent-to-solids ratio is established by the supplier, so that thinning is usually unnecessary. Cold paint should be warmed to the recommended temperature rather than thinned to reduce viscosity (Figure 5-1). Should thinning be necessary, the thinner should be of the type and amount specified by the supplier. The amount is not ordinarily more than one pint of thinner per gallon of paint.

With two-component paints, the viscosity of the mixed blend, not those of the individual components, is important. In such paints, the ratio of components, induction time, and pot life are critical features.

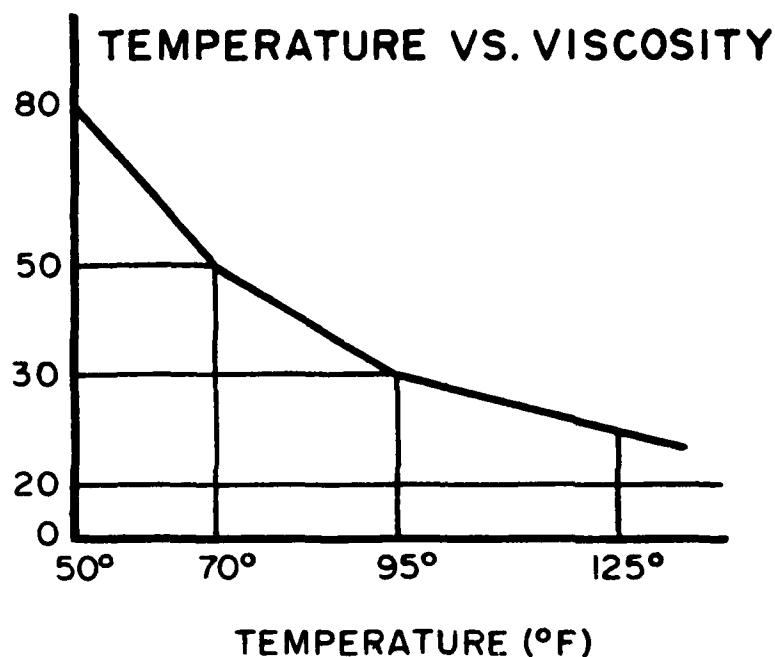


Figure 5-1. Temperature effect on viscosity.

Mixing

During storage, a relatively heavy paint pigment tends to settle and sometimes cake at the bottom of the can. Paint with settling must be mixed until restored to its original uniform consistency. Incomplete mixing of settled paints results in a *de facto* change of the formulation and may result in incomplete curing or inferior film properties. Thus, glass flakes remaining at the bottom of an incompletely mixed or partially settled vinyl-type high build glassflake modified paint such as Corps formula V-766e (with Formula V-113) will result in a glassflake-poor layer at the top of the pail and a glassflake-rich layer near the bottom. The glassflake-poor layer will not have the high build characteristics sought, and the flake-rich layer will generate a weaker film. Even though the paint may appear to be good, the effective protection of the substrate may have been compromised. Glassflake-filled, abrasive-filled, zinc-rich, and other heavily pigmented coatings must be constantly agitated during application. Coatings can be mixed manually or mechanically. Smaller amounts of paint (usually less than 5 gallons) are generally mixed manually, and larger amounts mixed by mechanical agitation.

Single-Package Mixing

Single package paints, such as alkyds and vinyls, are generally mixed as follows:

1. Pour the thin, upper portion of the settled paint into a clean container.

2. Stir the settled portion with a clean paddle to break up the settled pigment and to lift it from the bottom of the container.

3. Break the lumps by rubbing them against the inside wall of the can.

4. Mix the settled portion of the coating completely using a figure eight motion. Use a lifting and beating motion. When using a motor-driven mechanical mixer, move it around the interior of the container.

5. Gradually return the thin, upper portion to the original container with continuous stirring.

6. When paint appears to be well mixed, pour it back and forth between the cans, a procedure known as "boxing," until it reaches a smooth, even consistency. With a mechanical mixer, the paint should still be "boxed" to ensure no pigment lumps remain in the bottom of the mixing container.

No more paint should be mixed than can be applied the same day. The paint should not be allowed to remain in open pails or spray pots overnight. Unused portions should be combined and stored in a single, covered container. Coating should be remixed again before use during the following work period. If a "skin" forms on the surface, it should be removed prior to mixing.

Two-Component Mixing

Two-component coatings are particularly sensitive to temperature variations because the chemical reaction which causes the cure of such materials commences upon mixing of the components. This reaction is accelerated at higher temperatures. This fact effectively reduces the paint's pot life. (Pot life is the amount of time, after mixing of the components, during which the paint can successfully be applied.) Pot life is also affected by the size of the batch mixed, because the chemical reaction itself produces heat; thus the larger the batch, the greater the heat and the more accelerated the reaction. Conversely, the chemical reaction is slower, and correspondingly, the cure time is longer at lower ambient temperatures with smaller quantities. The most commonly used two-package paints are the epoxies and coal-tar epoxies. When the containers are of unequal size, the component of larger volume (A) is the base component, and the component of smaller volume (B) is the catalyst or curing agent. Unless the catalyst (Component B) is added to the base component (Component A), there will be no chemical reaction and no curing of the paint.

Once a two-component paint is properly mixed, the chemical reaction continues until the paint is fully cured. Unless completely used during the pot life of the material, the coating material will harden in the can, spray pot, lines, gun, and necessitate a difficult clean-up job and replacement of some of the items.

A two-component paint is mixed as follows:

1. Stir Part A with a clean paddle to disperse pigment lumps that may have settled.

2. While continuing to stir, slowly add all of Part B, which is frequently unpigmented.

3. Agitate the two combined parts until they are of smooth consistency, using either a manual or motorized agitator. Agitation should be sufficiently rapid to maintain the pigments in suspension, but should not be so fast as to entrain air into the coating.

4. If thinning is necessary, add a measured quantity of thinner to the Part B container and stir to remove any residual material. Add to Part A and continue stirring until completely blended.

5. All mixed coating with large particles or lumps remaining should be strained to prevent their clogging the spray equipment or alternately producing an unsatisfactory finish.

Many epoxy paints must stand for approximately 30 minutes before application for the chemical reaction to proceed; however, some materials react very quickly and can be applied immediately. This "induction time" can be extremely important for the complete curing of the coating. Once again, in two-component paints, only an amount of paint equal to that needed for immediate use should be mixed. Characteristically, a 5-gallon container will be used in about one hour of production spraying. Mixed paint remaining at the end of the shift cannot be reused and must be discarded. Only in rare cases is the pot life of two-component materials such that it can be used the following day. Because of this, applicators will often want to mix partial kits of material. This should be avoided whenever possible. However, if it is imperative that partial kits be mixed, graduated measuring cups must be used to assure that the proper mix ratio is maintained. Obtain the mix ratio from the coating manufacturer, not from the size of the cans, as the containers are often only partially filled. After mixing, tightly reseal the unused portions of material to avoid solvent evaporation.

Most epoxy coating materials require minimum temperature of the air, paint, and substrate of 50°F for complete curing. Above 90°F, the reaction time may be so rapid as to limit the effective pot life of the product.

Brushing

Brushing is an effective, relatively simple method of paint application, particularly with prime coating materials, because of its ability to work the paint into pores and surface irregularities.

Brushing is slow, and consequently is used primarily for smaller jobs; that is, surfaces with complex configurations (edges, corners, cuts, etc.), or where overspray may constitute a serious problem. The other drawback of brushing is that it does not produce a very uniform film thickness.

Natural brush bristles of good quality are preferred, but synthetic bristles resistant to the strong paint solvents may also be used. Bristles that are naturally or artificially flagged (i.e., with split tips) are preferred because they hold more paint. Nylon and polyester bristles are more water resistant than natural fibers and are preferred for latex paints.

Brush application of paint may leave brush marks with paints that do not level well. In addition, there will be areas of low film thickness. Even a second coat of the paint can leave the total system somewhat thin in areas, and these uneven areas can lead to early failure.

The application of a second coat of paint should be applied at right angles to the first in order to minimize possible overlap of thin areas from brush marks. Additional coats should be applied at right angles to the previous one.

Some tips for the proper use of a brush to produce a film of optimum quality and an acceptable appearance follow.

1. Shake loose any unattached brush bristles by spinning the brush between the palms of the hand.
2. Remove any stray bristles.
3. Dip the brush to cover one-half of the bristle length with paint. Too much paint may wet the heel of the brush and run down the handle.
4. Remove excess paint by tapping the brush on the edge of the can.
5. Paint with a light touch using the tips of the bristles rather than pressing down hard. This will minimize brush marks.
6. Always work from the dry to the wet area of the surface to avoid lap marks, and brush at about a 75° angle to the work.

Paint Mitt

A paint mitt can hold more paint than a brush, and is faster, but produces a very nonuniform thickness. Thus, paint mitts are generally used only for hard to reach areas or oddshaped objects such as small pipes and railings.

Rollers

Rollers are best used on large, flat areas that do not require the surface smoothness or uniformity achievable by spraying. Rollers are also used in interior areas where overspray presents a cleaning and masking problem. However, the brush is preferred over a roller for applying primer because of the difficulties in penetrating pores, cracks, and other surface irregularities. In rolling, air mixes with the paint and leaves points for moisture to penetrate the cured film. Rolling is generally more suitable for topcoating a primer which has been applied by some other method.

The nap (i.e., fiber length) normally varies from 1/4 to 3/4 in. A longer nap holds more paint, but does not give a smooth finish; thus, it is used on rough surfaces. Rollers with extra-long naps, i.e., 1-1/4 in., are used for chain link fencing. Handle extensions up to 10 ft or longer allow a painter to reach areas far away, but usually the net effect is a reduction in the quality of the application.

High-performance coatings for immersion are seldom applied by roller because of nonuniform thickness, wicking caused by roller residue, and rapid drying properties of some coatings, such as vinyl.

Some tips for proper roller use are as follows:

1. For thick-bodied coatings, dip the roller directly into the paint container. For thinner coatings, dip the roller into a roller tray.
2. For even application, the roller must be uniformly and properly loaded. Skidding or tracking may occur if the roller has too much or too little paint.
3. The roller should have enough material to provide the desired film thickness.
4. Do not apply heavy pressure.
5. Initially, apply the coating in a zig-zag overlapping direction to force the material into all sides of surface irregularities, but complete the application in one direction.
6. Apply the second coat at right angles to the first.

Spray Painting - General Methods and Techniques

Spray application of coatings results in a smoother, more uniform surface than that obtained by brushing or rolling, as these application methods tend to leave brush or stipple marks and irregular thicknesses.

The most common methods of spray painting are conventional and airless. They are briefly addressed below, but covered in more detail in following sections of this chapter. The conventional method of spraying relies on air for paint atomization. Jets of compressed air introduced into the stream of paint at the nozzle break the stream into tiny droplets that are carried to the surface by the current of air (Figure 5-2).

Because large amounts of air are mixed with the paint during application with conventional spray, paint losses from "bounce back" or "overspray material" that miss the substrate can be high and have been estimated to be as much as 30 to 40 percent, depending upon the configuration of the substrate. However, the ability to independently vary fluid and air gives conventional spray the versatility to provide a wide choice of pattern shapes and coating wetnesses by infinitely varying the atomization at the gun. Spray gun triggering is more easily controlled for precise spraying of irregularly shaped corners and pipes with airless spray.

Conventional spraying provides a finer degree of atomization and a higher quality surface finish than airless spray. Airless spray, on the other hand, provides a rapid film build, greater surface penetration, and rapid coverage.

In airless spraying, paint is forced through a very small nozzle opening at very high pressures to break the exiting paint stream into tiny particles (similar to water exiting a garden hose).

Because of the high fluid pressure of airless spray, paint can be applied much more rapidly and at greater film builds than in conventional spraying. The high pressure paint stream generated by airless spray penetrates cavities and corners with little surface rebound.

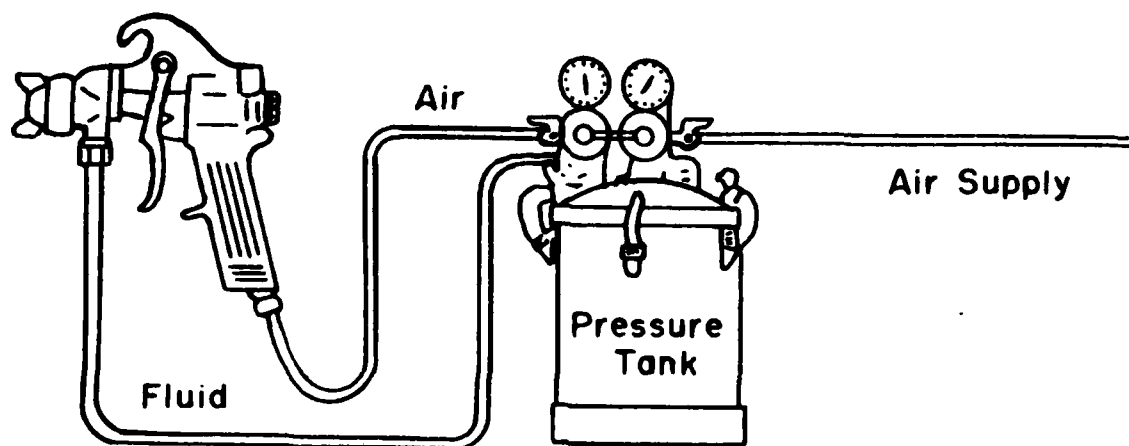


Figure 5-2. Conventional set-up.

This apparent advantage of airless spray in terms of high film-building characteristics is largely offset on Corps of Engineers projects, because CW-09940 requires that vinyls be applied in double spray coats consisting of banding plus two spray passes at a maximum dry film thickness of 2 mils per double spray coat. This 2-mil maximum requirement in combination with the double spray coat means that two layers of paint, each 1 mil in thickness, are to be applied. If fewer heavier layers are applied, pinholing, runs, sags, etc. are a likely consequence. Because of these requirements, many knowledgeable contractors use the more controllable conventional spray method of application for vinyls.

If airless spraying is used, proper spraying technique is essential for quality paint films. Poor technique can result in variations in paint thickness, holidays, and a host of other film defects in addition to wasted time and materials. Basic techniques are described later in this section.

Choice of Paint Application System

Most contracts will either specify the application method to be used or will permit the contractor to choose his own method. In the case of certain paints, however, the consistency of the coating may dictate only one particular method. Very viscous paints, for example, may not permit application by spray or, alternately, may only be applied by spray. Either the specifications or the manufacturers instructions will usually indicate the preferred method, or the only method allowed.

Conventional (Air) Spray Painting

Conventional paint spraying is a highly efficient method of applying high-performance paint systems and coatings to a substrate. Frequently referred to as "air

atomization," this method uses air to atomize, or reduce to a fine mist spray, streams of paint material under pressure. Material (paint) and air adjustments on the spray gun make it possible to apply intricate and variable spray patterns with a flick of the operator's hand. The gun can also be used to blast the surface with compressed air to remove dust prior to painting. This method's high versatility stems from a combination of air caps and fluid nozzles available for different coatings to be sprayed through the same basic spray unit. This application method also enables large amounts of material to be applied in very short periods of time.

However, some of the disadvantages of conventional air spray application are as follows:

1. It is slower than airless application.
2. More overspray results than with other methods.
3. It is hard to coat corners, crevices, etc., due to blowback.

Nonetheless, conventional spray is still one of the most frequently used methods.

Equipment and Materials. The following equipment and materials are required for conventional spray painting:

1. Paint materials to be mixed (then poured into paint pot)
2. Air compressor set-up
3. Oil and water extractor
4. Pressure feed tank (paint pot) or paint pump
5. Connecting hoses
6. Spray (air) gun.

Air Compressor. While the pot regulates both the air and fluid pressures reaching the spray gun (thus, a double-regulator), it is the air compressor that generates the necessary pressure for these two flow operations.

Air compressors can be of various types, with the size usually dependent on the amount of air required to operate the spray gun. Hoses must be properly sized to deliver the proper amount of air volume and pressure to the gun.

It takes approximately 40 to 60 psi and 8.5 CFM to operate most production spray guns with medium viscosity paint. If other air tools are also being used along with the spray equipment, the air pressure output may be reduced as well.

Oil and Water Extractor. Between the air compressor and the paint pot, an extractor should be set up to prevent moisture and oil from getting into the paint and ruining the quality of the finish. This component of the conventional spray setup should be considered as a standard item that cannot be absent because of potential paint and equipment damage. The use of properly sized and maintained moisture and oil separators helps to ensure the quality of the finished product. In addition to adhesion defects, oil or moisture in the compressed air will mix with the paint during atomization to create voids, pinholes, and fisheyes in the applied film.

Pressure Feed Tank (Paint Pot). The amount of fluid material delivered to the spray gun is regulated by the pressure set by the fluid pressure regulator of the feed tank pressure pot, which is a double regulator type. The pressure pot should be a 5 or 10 gallon size for most jobs. When painting tall structures, the pot should be kept at nearly the same level as the spray gun so that lower pot pressures can be utilized. Pressures in the 8 to 12 psi range at the gun are commonly used; excessive fluid pressure can cause the fluid stream to exit the fluid nozzle at too high a velocity for the air jets in the air nozzle to properly atomize the fluid stream. One alternative commonly used on Corps projects to minimize these effects is to use a paint pump to pump the paint from the pot to the gun. These pumps are commonly used with hot spray setups. In this case, the pump continually circulates the paint through a small electric heater which heats the paint (typically 70° F to 170° F, with 160° F quite common).

Hoses and Supply Lines. Two types of hoses are used in conventional air spray painting: air hose and fluid hose.

1. Air hoses (supply line): The hose from the compressor to the pot is usually red in color and should be at least 1/2 in. inside diameter (ID).

2. The air hose from the pot to the spray gun is also red and should be 1/4 to 5/16 in. ID and as short as possible.

3. Fluid hose: The fluid hose is usually black with a solvent-resistant liner. It should have a 5/16 to 3/8 in. ID for medium-viscosity materials and should also be as short as possible. For Corps formulations containing the glassflake additive package, a larger hose is required. Hoses up to 1/2 in. ID are commonly used. Excessive hose length allows the solids to settle in the line prior to reaching the spray gun. This leads to clogging and the application of non-homogeneous film.

Conventional Spray Gun. This application tool is used to "atomize" paint by mixing it with air under pressure in order to apply the coating material to the surface. By varying the volume of both air and fluid, the spray gun makes multiple spray patterns possible.

The selection of fluid nozzle and needle size is another way to regulate the amount of paint exiting the fluid nozzle. If excessive amounts of paint flow through the fluid nozzle at low pressures (8 to 12 psi), the fluid-adjusting knob can be used to reduce the flow, or a smaller fluid nozzle/needle combination may be needed. Paint manufacturers normally recommend at least one set of sizes known to work for their product.

Paints differ in the nozzle sizes they require for proper application, so that the paint manufacturer's recommendations should be followed. Also, air caps, fluid nozzles, and needle valves are not interchangeable, so only those manufactured for use in a given model gun should be used.

Figure 5-3 shows the features of a conventional (air) spray gun. It is important to understand how it operates in order to establish the proper adjustment for optimum coating application.

The air nozzle cap (A) is used to externally mix the paint with the atomization air as the paint comes through the fluid nozzle (B). This atomization air breaks the stream into droplets and provides the velocity for it to reach the surface. The pattern of the spray (round or oval) is determined primarily by air adjustments to the air cap and cap design. It is the needle valve (C) that regulates the amount of paint material through the

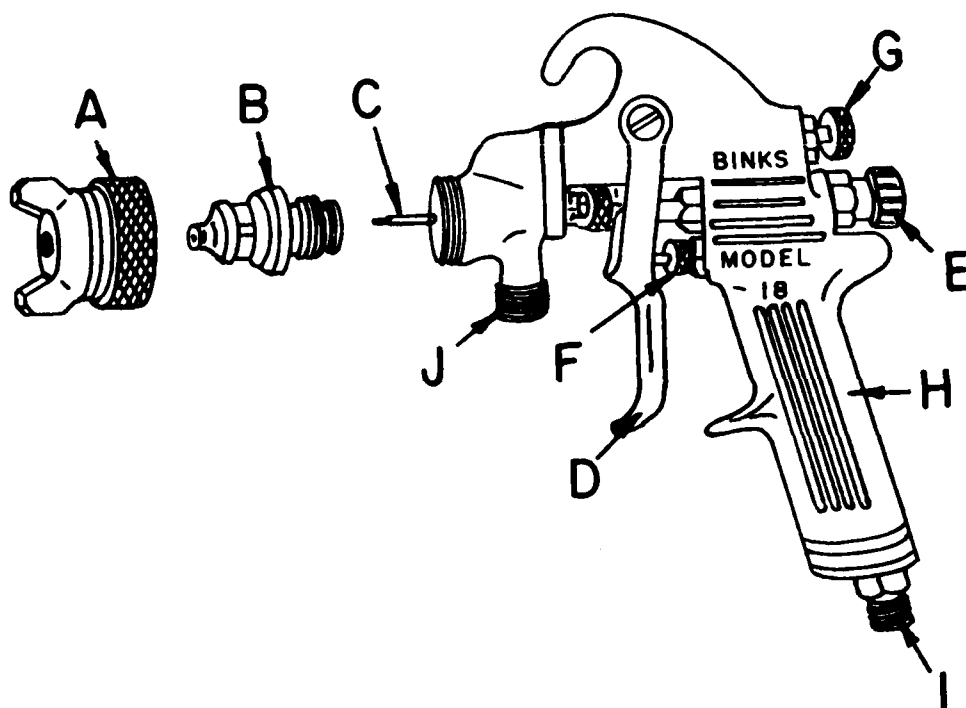


Figure 5-3. Conventional spray gun.

fluid nozzle. The distance the needle can be withdrawn from the fluid nozzle is controlled by the fluid control knob (E). The air valve (F) is operated by the gun's trigger (D), so that when the trigger is pulled, the air flow begins first and then the fluid flows. This is a major advantage of conventional spray. By half triggering the gun, the atomization air flows (without paint). This air stream is used to remove dust and loose debris from the surface and feather the paint. The side port control, or fan control (G), has the effect of regulating the fan pattern by means of adjustments of air volume that are required for a given job. Finally, the air connection (H), made normally of 1/4 in. NPS (National Pipe Straight) is the connecting point of the air hose; the fluid connection (I) provides an inlet in the body of the gun and is the connecting point for the paint material hose (normally 3/8 in. NPS). The different-sized fittings eliminate the possibility of making incorrect connections.

These features represent the working components of the conventional spray gun in which air is used to atomize the paint. All components must be correctly adjusted according to the manufacturer's directions for the paint being applied, and for the particular gun model used and for the conditions at the time the work is being performed. A gun adjustment which is suitable for one day (or person) may not be satisfactory for the next.

Conventional Spray Gun Adjustment.

Fluid Pressure Adjustments. The amount of fluid pressure for spraying a given coating varies with complexity of the item being painted, speed of painter, height of work above or below pot, temperature, size of hose, length of hose, etc.

The painting inspector should be familiar with the operational procedure involved in getting the correct fluid pressure to the spray gun:

1. Pour the mixed paint through a fine mesh screen into the pressure pot and clamp the lid on.
2. Turn on the air supply to the pot.
3. Turn on the fluid hose to the gun.
4. Turn off the air hose to the gun.
5. Remove the air cap from the spray gun.
6. Open the fluid control knob on the gun as far as it will go (the threads should be showing). Pull the trigger all the way back.
7. Hold the spray gun waist high, pointing it in a position parallel to the ground, and begin turning on the fluid pressure regulator on the pot.
8. Continue turning until a stream of paint shoots out of the gun for about three feet before it begins to bend. This is the proper fluid pressure.

Air Pressure. The air pressure at the spray gun is controlled by the air pressure regulator on the pot.

The pressure at the source, or line pressure, should usually be 100 to 135 lb. This pressure must be regulated at the pot as necessary to result in about 50-60 lb at the gun.

Thus, after fluid pressure has been correctly and adequately supplied to the gun, the operator must next turn on the air pressure according to the following steps:

1. Turn on the air to the gun.
2. Pull the trigger back.
3. Adjust the fan to about 8 to 10 in. wide by turning the pattern control knob (Figure 5-3).
4. Spray a test pattern by holding the gun about 6 to 10 in. from the surface and swinging rapidly to produce a coat.
5. If droplets of liquid hitting the surface appear to be less than 1/16 in. across (some coatings require finer atomization), air pressure is adequate and the paint will form a smooth, uniform coating. If spattered drops appear 1/8 in. or larger, the coating is not being atomized adequately. In this case, air pressure must be increased or paint thinned until droplets are 1/16 in. or less.
6. The lowest air pressure possible that provides the fullest atomization of air and paint should always be used to avoid painting problems, such as overspray.
7. After adjusting fluid and air pressures and establishing the spraying speed, make a final check of the applied coating using a wet film gage to be certain that enough

material is getting to the surface. However, when spraying fast drying vinyl materials, assessing wet film thickness is inappropriate, because very rapid solvent evaporation will give a meaningless reading.

Air Cap. While the arrangement, size, and angles of the air cap holes are determined by the type of paint being used, air nozzles are designed to use compressed air for externally mixing the paint material, or "atomization," in the following ways:

1. **Annular ring:** The space between the fluid nozzle and the air nozzle provides a column of air to surround the fluid stream. (The fluid stream expands and mixes with the air coming from the annular ring of the air nozzle, and is called "first stage atomization".)

2. **Containment holes:** These are in a straight line with the "wings" of the air nozzle. These holes keep the spray pattern from expanding too fast and keep the "wings," or "horns" clean.

3. **Annular converging holes:** These are a second set of air holes placed at 90 degrees from the containment holes. These air passages add additional force to help atomize the fluid stream, producing "second stage" atomization.

4. **Side port jets:** These are the air passageways in the wings of the spray nozzle. The purpose of these side port air jets is to form or shape the air and fluid stream into a "fan" shape to whatever dimension called for by the surface being painted. The size of the "fan" width (pattern) is controlled by regulating the amount of air diverted to the side port jets. The operator must turn the side port control knob until the desired pattern (small circle to long oval) is obtained.

Air spray gun nozzles fall into two basic categories: external mix and internal mix. The external mix nozzle produces the finest atomization and, if properly controlled, will give the best possible finish. The internal mix air nozzles do not produce very fine atomization and are generally used when a fine finish is not required or when only a low-pressure compressor is available. These nozzles are not widely used in maintenance painting.

Internal mix nozzles are limited to slower drying materials, because fast-drying materials tend to plug the exit hole. The air and fluid mix in a cavity inside the air nozzle. Upon release to the atmosphere, the material fans out in a pattern and the size of the fan is determined by the air nozzle opening. Selection of the nozzle is the only control which the operator has over spray pattern size and shape.

Spray Gun Techniques. Once the fluid and air pressures have been properly set and the gun is adjusted for the correct amount of spray, there remain several basic spray techniques (involving type and size of spray patterns) that the inspector must be aware of in order to assure a good paint job.

1. **Spray Pattern**--A vertical spray pattern 8 to 10 in. wide should be created by adjusting the control knob (see Figure 5-3). The control knob should be turned to the right (clockwise) for a round pattern and to the left for a fan pattern.

2. **Nozzle Position**--A vertical fan shape spray pattern allows for the best coverage as the spray gun is moved back and forth in a parallel motion to the surface being sprayed. To obtain a vertical fan spray pattern, the "wings" of the nozzle should be positioned horizontally with respect to the vertical work surface.

3. Stroking--With the spray gun at a right angle to the work, the wrist, arm, and shoulder are parallel to the surface. This technique, called stroking, prevents "arcing," which is varying the distance of the gun to the surface which results in a nonuniform coating thickness (see Figures 5-4 and 5-5). For large flat areas each stroke should overlap the previous one by 50 percent. This produces a relatively uniform coating thickness.

The stroke length should be from 18 to 36 in., depending on the arm length. Areas of greater length should be divided into smaller sections of appropriate length. These sections should slightly overlap the previous ones along the lines where they are joined (Figure 5-6).

The Corps of Engineers requires a "double spray coat" on most coatings systems employed. This "double spray coat" consists of a banding pass (see Item 7 below), followed by two complete wet spray coats using a 50 percent overlap, followed, after drying to a tack-free condition, by another full wet spray coat at right angles (if practical) to the first.

4. Triggering--The spray gun should be triggered at the end of each pass. At the beginning of a pass, the gun should be in motion prior to triggering, and the motion continued briefly after releasing the trigger at the end of the stroke. The resulting gun control produces a uniform, continuous film. Proper triggering also reduces paint loss, prevents heavy build up of paint at corners, edges, and at ends of strokes, eliminates the build up of fluid on the nozzle and tip; keeps them clean, and prevents runs and sags at the start of each stroke.

5. Speed--Spraying at a constant speed results in the application of a full wet coat of uniform thickness. The slowest stroke deposits a thicker coat while a faster stroke produces a thinner film. If very rapid stroking is needed to prevent flooding, the fluid nozzle is probably too large or the fluid pressure too high. If very slow stroking is needed for a wet coat film with good leveling, the fluid pressure is probably too low or the fluid nozzle too small. Speed and rhythm required for quality paint spraying are developed with experience.

6. Distance--The amount of material delivered at any given atomization pressure determines the proper gun to surface distance for a uniform wet film. It generally varies from 6 to 10 in. for conventional spray, and from 12 to 16 in. for airless spray. If the spray gun is held too close to the surface, heavy paint application and sagging or running may occur. If the gun is held too far from the surface, too dry a film with a sandy finish may result. Such paint films usually contain holidays or microscopic pores through the coating.

7. Banding--Banding should be used to reduce overspray caused by trying to spray right up to the edge with horizontal strokes. (Here the ends should be sprayed with vertical strokes, while the middle section in between gets horizontal strokes.) CW-09940 requires the application of a preliminary, extra spray pass not only on edges but also on corners, interior angles, seams, crevices, junction of joining members, rivets, weld lines, and similar surface irregularities. After this banding, a full double spray coat is then applied as if no banding had been done.

8. Long Sections--If long sections are to be sprayed, then the work should also be divided into convenient sections by the operator; also these sections should overlap 3 to 4 in. so that a uniform coating effect is produced.

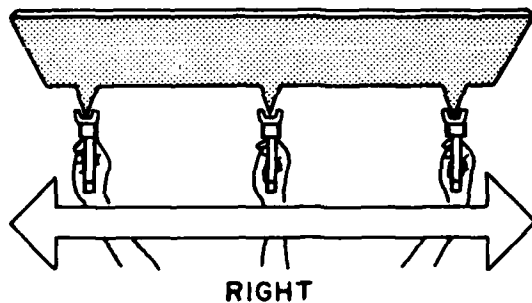


Figure 5-4. Proper spray gun stroke.

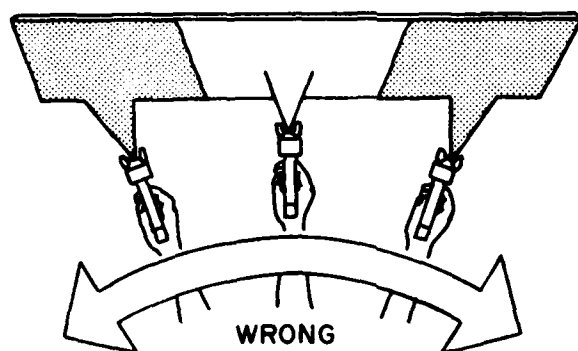


Figure 5-5. Improper spray gun stroke.

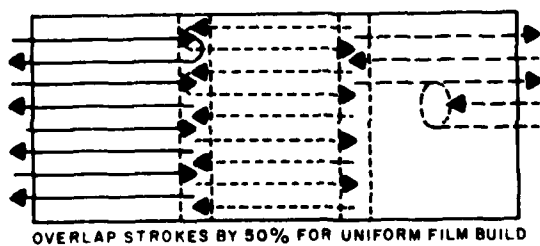


Figure 5-6. Proper overlapping technique.

9. Slender Sections--When a slender job is being sprayed, inspect to make sure the spray pattern fits the job to avoid unnecessary overspray (Figure 5-7).

10. Inside Corners--To correctly spray inside corners, each face should be sprayed separately with strokes going right up to the corner (Figure 5-8). Since inside corners are frequently welded joints with surface roughness, they may also be sprayed by cocking the gun at a 45 degree angle and spraying directly into the corner. Care must be taken, or the result will be excessive paint buildup in the corner.

11. Outside Corners--Outside corners should first be banded as in Item 7 above. The double spray coat should then be applied as follows. The corners should be sprayed square-on, then each face should be sprayed with strokes going right up to the corner to provide adequate coverage.

12. Panels--Panels should be painted by using right and left strokes. The spray pattern should overlap one-half the previous stroke for smoother coverage without streaks (Figure 5-9). The second layer of a double spray pass should be applied at right angles to the first if possible. This cross-hatch pattern will assure more complete coverage.

13. Round Work--Round work is best sprayed with a round spray pattern (Figure 5-10). On vertical work, use a vertical stroke in a deliberate mechanical manner, keeping a constant distance from the work piece. Use 50 percent overlap on each pass to obtain full, even coverage. On horizontal work, the same method should be employed, except that the passes should be horizontal.

14. Open Work--Open work should be sprayed to get the most coating on the largest area at each stroke. Grills and lattice work should be sprayed with a single up and down stroke on each side. The gun should be held at an acute angle to cover as much of the work as possible with each stroke.

15. Pole Guns -At times, there will be areas where a conventional spray gun will not reach. In these areas, a pole gun that attaches directly to the air and fluid hoses may prove useful. The model shown in Figure 5-11 is an example of a pole or extension gun that comes in 4, 6, and 8-ft lengths. The head of this model is set at 45 degrees and can be rotated to suit the job. The spray pattern is adjustable from round to broad fan.

The disadvantages of pole guns are also apparent. When one applies a coating 4, 6, 8, or more feet away, it is very difficult to assure full uniform coverage free of runs, drips, sags, etc. On Corps of Engineers projects using vinyl paints, this lack of control can result alternately in holidays and heavy areas. These heavy areas will likely contain extensive pinholing.

16. Nozzle Extensions--Also useful for painting in hard-to-reach areas are nozzle extensions that attach directly to the spray gun (Figure 5-12). These models range in length from 6 to 84 in.

Inspection Checklist for Spray Paint Application. The following list of spraying procedures gives the painting inspector an overall view of minimal steps to be followed by the spray gun operator.

1. Only surfaces should be painted that have been cleaned on the same day.

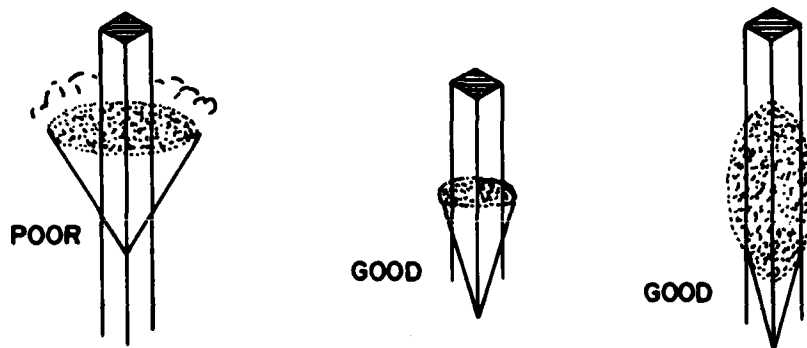
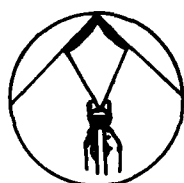


Figure 5-7. Slender work—center method best for most jobs.



a. Inside corner sprayed square on.



b. Birds eye view of outside corner.

Figure 5-8. Spray painting corners.

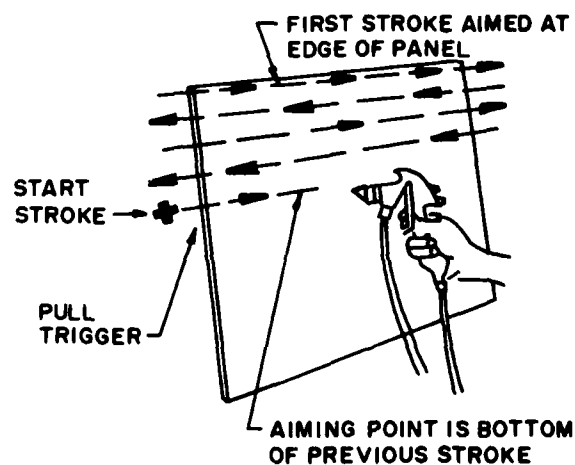


Figure 5-9. Spraying a panel.



Figure 5-10. Spraying round work.

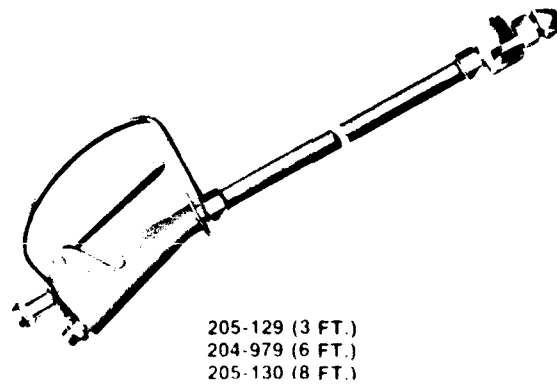


Figure 5-11. Pole gun.

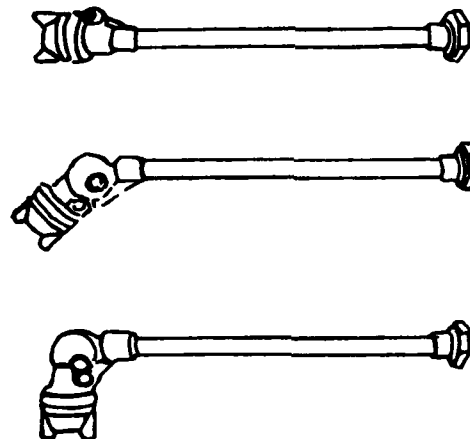


Figure 5-12. Nozzle extension.

2. All sandblasting sand and residue must be completely removed before painting begins and no sandblasting should be done in the paint work area.
3. The lowest possible air and fluid pressure must be used when a spray gun is being operated. Excessive pressures create runs, sags, and overspray.
4. The spray gun should be operated with the fluid control adjustment wide open on flat, smooth surfaces.
5. The proper fan width for the job should be used.
6. Spraying from the proper distance (6 to 10 in.) is crucial.
7. The spray gun should be held perpendicular to the work for the entire spray stroke.
8. The spray gun must be kept parallel to the work surface for the entire spray stroke.

9. A speed which assures a full wet coat for the work surface must be maintained by the operator.

10. Ends of strokes must be feathered by "triggering."

11. Strokes should always overlap at least 50 percent.

12. All hard-to-reach areas must be adequately covered (such as backs of rivets, bolts, frayed areas). These are areas where corrosion starts.

13. Proper amounts of paint must be applied so that the dry film thickness will sufficiently cover peaks of anchor pattern. This amount should be determined during application through the use of wet film thickness gages where appropriate.

14. All paint must be applied correctly (using the proper spraying technique) to avoid such problems as overspray, dry spray, etc.

15. Signs should be posted to warn traffic of painting work ahead.

16. All documentation and record forms should be filled out by the inspector at all points during operational inspection checks.

In addition to the above, the painting inspector should be generally familiar with the various components of the spray gun controlling the fan pattern of the paint spray. The previous section and Figure 5-3 furnish a model which demonstrates the various adjustable parts of an air spray gun. Knowledge of the gun will help the inspector determine what adjustments are necessary to produce given spray patterns.

Spray Pattern and Gun Problems. The following problems may be encountered by the spray operator; some possible solutions are given under "Correction."*

Problem: Dried material in side port "A" restricts passage of air through port on one side. This results in full pressure of air from clean side port into the fan pattern in the direction of clogged side (Figure 5-13a).

Correction: Material should be dissolved in side port with thinner. Openings in clogged side of air cap should not be probed--this may ruin it. It is best to have clogged nozzle brushed with solvent. If probing is the only alternative, use a soft material such as a toothpick (Figure 5-13b).

Problem: Dried material around the outside of the fluid nozzle tip at position "B" restricts the passage of atomizing air at one point through the center by a loose air nozzle, a bent fluid nozzle or needle tip, or a stopped-up hole (Figure 5-13c).

Correction: If dried material is causing the trouble, the air nozzle should be removed and the fluid tip cleaned with rag and solvent. The air nozzle should then be tightened. The fluid nozzle or needle, if bent, should be replaced. Holes should be cleaned with a straw or flexible materials. Never allow hard material to be used in cleaning: this will enlarge holes (Figure 5-13d).

*Taken from *Air Spray Manual*, TD10-2 (Binks Manufacturing Company, 1976).

Problem: "Splitting" is the rhythmic stopping and starting of material flow, caused by: air entering fluid supply, dried-out packing around material needle valve that allows air to get into fluid passageway, dirt between the fluid nozzle seat and body or a loosely installed fluid nozzle, or a loose fluid line connection at the pot or gun (Figure 5-13e).

Correction: Make sure all fittings and connectors are tight. Packing nut "E" should be hand-tightened if it is just loose. (DO NOT use a tool to make nut tighter.) Oil pack or replace if necessary. Fluid nozzle "F" should be removed so that back of nozzle and nozzle seat can be cleaned with rag and solvent (Figure 5-13f).

Problem: Fan pattern is heavy in the middle or has an unatomized "salt-and-pepper" effect. This indicates that the atomizing air pressure is not high enough, or too much material is being fed into the gun (Figure 5-13g).

Correction: Atomizing air pressure should be increased at pot. If caused by excessive fluid, a smaller fluid orifice should be used (Figure 5-13h).

Airless Spray Paint Application

Airless spray equipment provides higher film build capabilities and handles products formulated in high-viscosity systems without dilution through the addition of large quantities of solvent. Instead, hydraulic pressure is used to force paint through an orifice (small hole) in the spray nozzle. The high degree of pressure atomizes the paint as it is discharged through the spray nozzle without the need for any mixing with air. As the fluid (paint material) is released under these pressures (400 to 4,500 psi), it breaks up into small droplets resulting in a fine atomized spray.

Some coatings and paints, especially the latex materials, are difficult to atomize hydraulically. With these, finer atomization is produced by inserting a secondary orifice, or "preorifice," between the valve and the nozzle--this greatly increases turbulence in the fluid stream, which then aids in the fluid breakdown into droplets. The preorifice size should be larger than the nozzle size.

Advantages. Below are some of the advantages of airless spraying as compared with conventional.

1. Higher film build possible (heavier coatings).
2. Less fog or rebound than conventional (air) spray.
3. Easier to use by the operator because there is only one hose.
4. Good results on large surfaces because of speed of application.
5. Higher-viscosity paints can be applied.
6. Easier clean up.

Disadvantages. Below are some of the disadvantages of airless spraying.

1. Relies on dangerous high pressure.
2. Fan pattern is not adjustable.

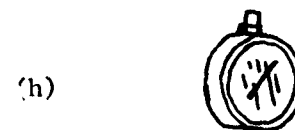
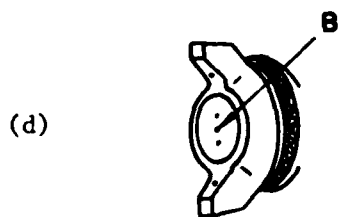
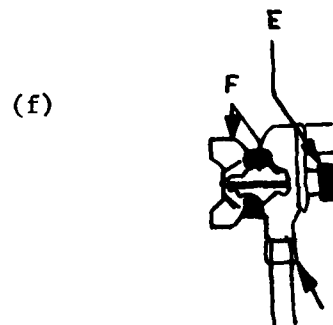
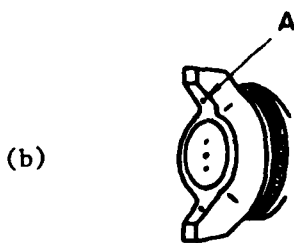
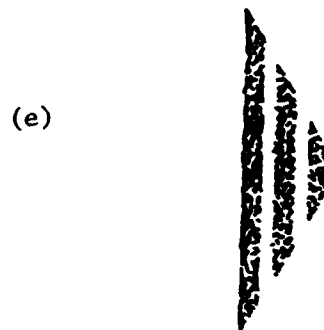


Figure 5-13. Conventional spray paint application problems and solutions.

3. Many more working parts that can cause difficulty.
4. Tip clogs more easily.
5. Higher initial cost than other forms of spraying.
6. Requires special care to avoid excessive buildup of paint that causes solvent entrapment, pinholes, runs, sags, and wrinkles.

Equipment and Materials. An airless spray system requires:

- Power source (an electric motor or air compressor).
- Air hose and siphon hose.
- High-pressure fluid pump with air regulator (if a compressor is used).
- A fluid filter.
- A high-pressure fluid hose.
- Airless spray gun with nozzle tip.

Power Source

Electric Motor. This may be used instead of an air compressor to drive the fluid pump. The "electric airless" is a self-contained spray outfit mounted on wheels and designed to use commercial 115-volt electrical power.

Air Compressor. Usually a 1-horsepower, 100-psi electric motor or 1-1/2-horsepower gasoline engine is required to operate one gun with 0.018 in. tip. For two or more guns or heavy materials, greater capacity is needed.

Air Hose and Siphon Hose. A 1/2 in. (7/16 in. min.) inside diameter (ID) hose is generally used to deliver air from the compressor to the pump. Fifty feet is the most common hose length. However, as hose length and pump size increase, the inside diameter of the hose must be increased as well.

A siphon hose, if required, must be 1/2 to 3/4 in. ID to provide adequate fluid delivery. Also, the hose material must be resistant to the fluid solvent and other materials. A paint filter should be used to prevent dirt from clogging the fluid hose and tip. In some cases, this hose is eliminated, and the pump is immersed directly into the paint.

Pump. The fluid pump is the most important part of the hydraulic airless system; it multiplies the air input pressure to deliver material at pressures up to 4500 psi. Air-operated pumps are offered with delivery ranges from 28 oz./min. (1 gun) up to 3 gal/min (3 to 4 guns). The pump used for many airless outfits will convert 1 lb of air input into 30 lb of material pressure. This is referred to as a 30:1 ratio. Pump ratios as high as 45:1 are common.

Some airless spray units use an electric-hydraulic power pack. These units can supply two guns with airless spray tips of up to 0.021 in. orifice and long spray lines, or one gun for high-volume delivery with an airless tip of up to 0.031 in. orifice. These

electric units are wheel-mounted and use a long-stroke, slow-speed pump. The unit is equipped with an explosion-proof motor and can deliver as much as 1 gpm at pressures up to 3000 psi.

In an airless pump, the air motor piston reciprocates by alternate application of air pressure on the top, then the bottom of the piston. The air motor piston is connected directly to the fluid pump with a connecting rod. The fluid section, or pump, delivers fluid on both the up and down strokes. This is why it is called a double-action pump.

Paint (Fluid) Filter. A paint filter should be attached to the pump at the fluid hose connection. The filter prevents dirt and particles from clogging the gun and being sprayed onto the work surface.

High-Pressure Fluid Hose. The airless pump filter hose is made to safely withstand high fluid operating pressures. It is made of vinyl-covered, reinforced nylon braid and can handle about 4500 lb of pressure. The hose is designed to resist the solvent action of the various coatings being sprayed. A wire is often molded into the hose assembly to prevent any possible static electrical charge. The gun should be equipped with a high-pressure swivel to accommodate any normal twisting action of the hose. The inside diameter should be at least 1/4 in. and the length should not be longer than necessary to do the work, ideally 50 to 100 ft. Fluid hose diameters up to 1/2 in. are commonly used.

Spray Gun. The airless spray gun is designed for use with high fluid pressures, and is similar to a conventional gun in appearance, but has a single hose for the fluid. The hose may be attached to the front of the gun or to the handle. The resulting "airless spray" or atomization, happens when fluid is forced through the small orifice in the spray cap at high pressures.

The spray gun typically has an aluminum or brass body and a stainless steel needle assembly with a Tungsten carbide needle tip. A fluid needle safety lock prevents the gun from operating when the spray tip assembly is being changed.

A variety of spray tips are available to suit the type of material being sprayed and the size of spray pattern desired. The hole in the tip and the fan angle control the pattern size and fluid flow. There are no controls on the gun itself. Tip orifices (holes) vary in range to fit the thickness (viscosity) of the paint being applied while fan angles range from 10 to 95 degrees.

The quantity of paint sprayed is determined by the orifice size; the larger the orifice, the more fluid it can deliver at faster speed; however, poorer atomization results.

The applied thickness and pattern size are determined by the orifice and the fan angle (and spray speed). Two nozzle tips having the same orifice, but different spray angles, deliver the same amount of paint over a different area width.

CW-09940 permits the use of hot airless for vinyl coatings, provided that "dual or adjustable" tips are used. Dual tips are often ball tips with two separate painting orifices. This feature provides the ability to spray two different size spray patterns--a narrow fan for narrow surfaces and a wide fan for wide areas. Adjustable tips provide a varying spray fan while simultaneously varying the tip orifice. Note that as fan width increases, tip size also increases. If a wide fan is required and too much paint comes out, it will be necessary to use a smaller tip number. For instance, one such unit (Titan Tip--Titan Tool, Inc., Oakland, NJ) is adjustable from 0.017 in. orifice with a 4 in. fan to a

0.035 in. orifice with a 24 in. fan. If a 24 in. fan were required, but with a 0.025 in. orifice, a different tip would have to be used.

Airless Equipment Adjustment. Each airless spraying unit has its own instructions supplied by the manufacturer, but the basic procedures typical for such a setup are:

1. The air supply hose should be connected between the air inlet on the pump and the air supply.
2. The high-pressure fluid hose should be connected between the filter manifold (or pump outlet) and the spray gun.
3. The regulator adjustment must be backed off, then the main air supply valve opened to the regulator.
4. The fluid pump or siphon hose should be immersed in a container of solvent.
5. The air regulator adjustment should be turned on until the pump begins to operate slowly.
6. The spray should be directed into the solvent container and then the trigger pulled.
7. The air regulator should be increased and the pump run for 1/2 minute at moderate speed.
8. Check all hose connections for leaks.
9. The siphon hose or fluid pump should be removed from solvent.
10. The regulator should be opened next and the system should be allowed to pump out solvent.
11. Air should be allowed to flow through the system for about 1/2 minute in order to empty the system of solvent.
12. Check agitator and other air-operated accessories for proper functioning.
13. Next, have the inlet shut off.
14. The paint should be strained into the paint container.
15. The siphon hose should be immersed in the paint, or the pump placed on top of the container.
16. Last, the proper spray tip should be selected before beginning work. The coating manufacturer will normally recommend target tip sizes for typical applications. Fan width is normally selected to suit the type of surface being coated (see Item 2 below).

All of these checklist items are extremely important for the smooth functioning of the entire airless system and the inspector should make sure they are all in good working order and hooked up properly. Given the nature of the airless high-pressure hydraulic system setup, very little error can be tolerated without endangering personnel and the work.

1. A variety of tip sizes should be on hand when an assortment of paints are to be used.

2. As a rule, if a wide angle, or broad pattern, is desired, a 65 degree angle spray tip should be used. If a smaller, or narrower pattern is needed, a tip with a 25 degree angle or spray should be used.

3. After the proper spray tip has been selected, the air pressure into the pump should be adjusted to the lowest pressure to produce a fully uniform spray pattern.

4. If not enough air pressure is applied, streaks or fingers will result. Gradual adjustment of the air pressure will reduce the streaks; when correct operating pressure is reached, the spray will even out into a balanced pattern.

Preventive Maintenance. Because airless equipment operates under such high pressures, the inspector's first duty is to make sure all equipment is in satisfactory operating condition. One way this can be done is for the inspector to encourage the operator to keep equipment in good working order and then to check before each work shift to see that this has been done.

Some of the recommendations for such upkeep procedures may be listed as follows:

1. Check the air regulator and diaphragm for damage. Inspect the filter and valve for cleanliness.

2. Check the high-pressure hose for ravelled braiding and damaged hose connections.

3. Check the fluid filter for clogged or broken mesh screen. Fluid filters containing either 30 or 60 mesh filter screen are common.

4. Check the gun cartridge, ball seat, packing, spacers, etc., for damage and wear.

5. Check the fluid pump for damage, worn packing, and worn piston cylinder.

6. Check the air motor for damage, worn piston rings, scored cylinder walls, etc.

Spray Techniques. The same spray-painting techniques used for conventional spraying (air) are used for airless spraying, except for the following:

1. The air supply to the pump should be opened and the pressure regulator increased until an adequate spray atomization can be obtained at the gun. If proper atomization cannot be achieved, the coating could be heated or thinned (to approximately 35 to 40 seconds for conventional spray and 50 seconds for airless spray using a #4 Ford cup at 72° F for vinyls).

2. The gun should be moved parallel to the surface at a distance of 12 to 16 in. (whereas conventional air spray is from 6 to 10 in.).

3. The overlap for producing uniform thickness of film should be 50 percent.

4. Proper speed of movement in spraying should provide a full wet coat application with each stroke. If the stroke speed is allowed to be very fast in order to avoid

flooding, then the fluid nozzle orifice is too large or the pressure is too high, and either must be changed. (Also, if the stroke speed is very slow in order to get adequate coverage, then the fluid nozzle is too small or the fluid pressure is too low.) (Note: A major problem with vinyl coatings application is the occurrence of pinholes. The causes of pinholing and some remedies are discussed in Chapter 7.)

Spray Pattern and Gun Problems. Some of the typical airless spraying problems known to occur with suggestions for correction are given below.

Problem: Tails (Figure 5-14a).

Cause: Inadequate fluid delivery, fluid not atomizing.

Correction: Increase fluid pressure, change to smaller orifice tip size, reduce fluid viscosity, clean gun and filter(s), reduce number of guns using pump, or install properly matched sapphire insert.

Problem: Heavy centered pattern (Figure 5-14b).

Cause: Worn tip, or fluid not spraying with airless.

Correction: Replace tip, or change to air atomizing.

Problem: Distorted Pattern (Figure 5-14c).

Cause: A plugged or worn nozzle tip.

Correction: Clean or replace nozzle tip.

Problem: Pattern expanding and contracting (surge) (Figure 5-14d).

Cause: Pulsating fluid delivery, insufficient air supply to pump, a leak in suction tube, pump capacity is too low, or material is too viscous.

Correction: Change to a smaller tip orifice size; install pulsation chamber in system, or drain existing one; reduce number of guns; increase air supply to air motor; remove restrictions in system; clean or remove screens or filters; use larger hose or pump if necessary; inspect siphon tube and hose assembly for leak; or reduce fluid viscosity.

Problem: Round pattern (Figure 5-14e).

Cause: Worn tip; or fluid too heavy for tip, or fluid not spraying with airless.

Correction: Replace tip, increase fluid pressure, thin material, change nozzle tip, install sapphire insert, or change to air-atomizing system.

Problem: Hour glass (Figure 5-14f).

Cause: Fluid too cohesive (adhesive type); or fluid not spraying with airless.

Correction: Increase fluid pressure, thin material, install sapphire insert, or change to air-atomizing system.

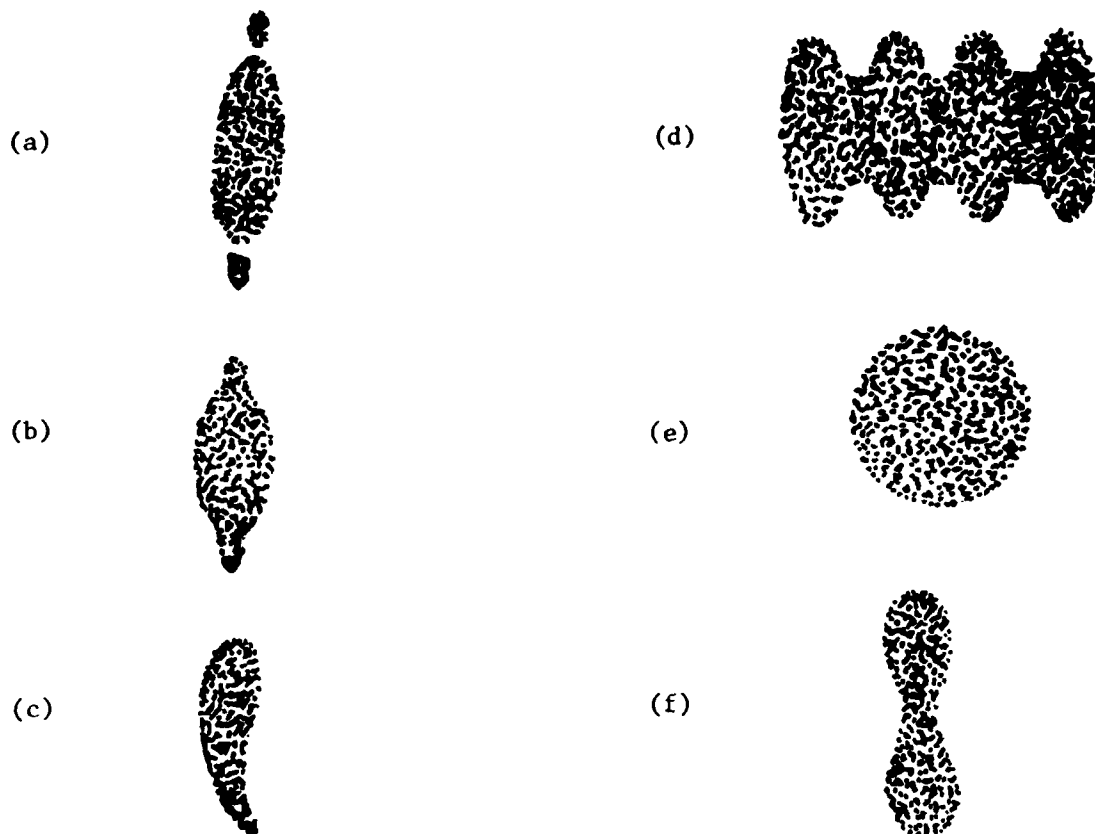


Figure 5-14. Common airless spray problems.

Safety Precautions. Several safety precautions are important when using airless spraying.

1. Never, under any circumstances, allow the spray gun to be carelessly handled, or its spray aimed at any part of the human body. (Note: The fluid under high pressure can penetrate the skin and cause serious injury.)

2. Never permit the hose or spray gun to be removed before the pressure is released from the outfit. (Note: Shutting off the power does not by itself relieve fluid pressure.)

3. Before attempting to change the spray tip or gun, make sure the pressure has been relieved or the spray gun trigger locked. (Note: The pressure could shoot the nozzle tip like a bullet and cause injury.)

4. Never allow the use of conventional fluid hose with airless equipment; it is not designed for high pressures. Make sure special high-pressure nylon braided hose is used. The hose must be free of kinks and frayed areas. Inspect such hose before each use.

5. Hose connections, joints, and seating surfaces on the spray gun should be carefully handled to prevent damage to the seating surfaces.

6 INSPECTION

The purpose of inspecting field painting is to ensure quality control over paints and paint application. For contract work, it ensures that all specification requirements are met. Thus, the inspector must be thoroughly familiar with these requirements as well as the necessary inspection procedures to determine whether they are met. An inspector must deal with facts, not opinions; precise data, not estimates; specifications, not speculations. Duties encompass:

- Inspection of materials
- Inspection of surface preparation
- Inspection of paint application
- Final inspection for acceptance.

The inspector's job is to enforce the specifications as precisely as they are written. He* should not enforce anything other than that called for by the specifications, nor should he assume individual responsibility for altering or modifying the specifications. His training is usually not that of a corrosion engineer or a paint formulator, and he is not expected to know all the answers. The best coating inspectors are well informed and confident: they recognize the limits of their knowledge and experience, and know when and how to get help to resolve problems on the job.

Any apparent errors, omissions, or potential problems with the specification should be brought to the attention of the contract officer or work supervisor, since the contractor is required only to meet the written requirements. The specification must include and define the requirements for materials (i.e., specifications, testing, quality, age, etc.); surface preparation (i.e., standards for cleaning, the procedures for determining it, equipment to be used, etc.); application (i.e., equipment to be used, wet or dry film thicknesses, temperature, humidity limitations, etc.); and appearance (i.e., uniform color, gloss, and texture with no holidays, runs, sags, etc.). Painting inspection usually costs from 1 to 5 percent of the contract amount. It is an important investment. The inspector's daily records form an important part of the permanent records on each structure, vessel, or component which is painted.

Inspection of materials at the jobsite can identify deficiencies that would result in unsatisfactory painting unless corrected.

Safety Considerations

Every painting assignment exposes coating personnel to conditions and situations which contain actual or potential hazards to themselves and to others in the area. The frequent use of toxic and flammable materials, pressurized equipment, ladders, scaffolds, rigging, and other typical "tools of the trade" always present a potential hazard. Hazards may also be inherent to the very nature of the environment or be caused through ignorance or carelessness of the operators. It is therefore extremely important to be aware of all potential hazards since continuous and automatic precautionary measures

*Male pronoun is used to represent both genders.

will be required to minimize the problems and improve efficiency, morale, and assure a safe job for the entire painting crew.

Inspection Sequence

Inspection often begins with a prejob conference at which the ground rules are set. But when the actual work begins, the inspector is responsible for witnessing, verifying, inspecting, and documenting the work at various inspection points. At least the following points should be observed:

- Pre-Surface Preparation Inspection
- Measurement of Ambient Conditions
- Evaluation of Compressor (Air Cleanliness) and Surface Preparation Equipment
- Determination of Surface Preparation, Cleanliness, and Profile
- Witnessing Coating Mixing
- Inspection of Application Equipment
- Inspection of Coating Application
- Determination of Wet Film Thickness
- Determination of Dry Film Thickness
- Evaluation of Cleanliness Between Coats
- Pinhole and Holiday Testing
- Evaluation of Adhesion and Cure

Pre-Surface Preparation Inspection

Before surface preparation and other coating activities it is necessary to inspect to determine if the work is ready to be prepared and painted. Heavy deposits of grease, oil, dust, dirt, and other contaminants must be removed. Removal of this miscellaneous debris prior to blast cleaning assures that these materials are not redeposited onto the freshly blast-cleaned surfaces. These contaminants are removed by following the steps outlined in the Steel Structures Painting Council Specification SSPC-SP1 "Solvent Cleaning." The requirements of SSPC-SP1 are included by reference in all SSPC cleaning specifications including Hand Tool (SP2) and Power Tool (SP3) cleaning specifications.

In addition, the specifications may require that weld spatter be ground or otherwise removed and sharp edges be rounded (customarily to a 1/8 in. radius). Unusual pitting in the steel substrate should be examined and dealt with at this time. The pits can either be accepted as they are or required to be ground or filled. Adjacent areas not required to be cleaned or coated should be masked at this time to protect them from the cleaning and coating operation.

Ambient Conditions

Before "final" blast cleaning and before any paint is applied, the inspector or painter should check the "ambient" or surrounding weather conditions. This is especially important in the early morning when the weather is changing or during seasonal changes when condensation is common. The presence of a thin film of condensed moisture on the surface may be imperceptible visually, but a quick check of the dewpoint and the surface temperature will determine if such a moisture condition exists. Dewpoint is defined as the temperature at which moisture condenses on a surface. If the dewpoint is found to be 60° F, moisture will condense on the surface if it is 60° F or colder. However, due to instrument inaccuracies, changing weather conditions across a structure, and human error, the industry usually stipulates that "final" blast cleaning and paint application should only be done when the surface temperature is at least 5° F greater than the dewpoint.

Dewpoint is not read directly from a gage, but is calculated using temperature readings from a psychrometer and appropriate psychrometric tables. A psychrometer is a hand-operated or motorized instrument used for determining relative humidity and dewpoint. The instrument contains two glass thermometers, one of which has a clean cloth "sock" or "wick" on it. This bulb is called the "wet bulb" and the other the "dry bulb" (ambient temperature). The thermometer with the "sock" is thoroughly wetted with ambient temperature water, and air is circulated around both thermometers either by whirling the sling psychrometer or switching on the fan of the motorized instrument. Whirling should occur with a steady, medium speed. When the temperature of the wet-bulb thermometer stabilizes (three consecutive readings at the same temperature or about 2 minutes with the motor-driven instrument) the temperatures of both are recorded. The readings are then plotted on a psychrometric chart or table to obtain the dewpoint and relative humidity.

Psychrometric tables are calculated at different barometric pressures. If the barometric pressure is unknown, the 30-in. pressure table should be used.

To complete the assessment of ambient conditions, the surface temperature must be measured. The temperature of a steel surface is best measured by a thermometer with a magnetic clip to hold it in place. One common instrument consists of a bimetallic sensing element that is shielded from drafts. It requires about 2 minutes to stabilize. For nonferrous surfaces, the thermometer can be taped to the surface. Other instruments include thermocouples, which provide rapid, accurate measurements of surface temperature.

With any of the instruments used for determining ambient conditions and surface temperatures, the readings should be taken at the actual work locations. For general readings, however, one should consider the coldest point on the structure because a surface temperature/dewpoint relationship problem will occur there first. Air and surface temperature considerations are also important to ensure that coatings are not applied outside their temperature limitations--in areas too cool or too warm. Accordingly, readings for this purpose should be made at the coolest or warmest areas. Note that while the assessment of dewpoint and humidity are important to the obtaining of the ultimate in quality, there are times that the situation dictates that the conditions cannot be maintained. For example, it may be impossible to control the environment on a dam gate close to the water behind a leaking bulkhead. In this case, all that may be possible is a "best effort." However, this does not justify total disregard of the ambient conditions elsewhere on the project.

Evaluation of Compressed Air Cleanliness and Surface Preparation Equipment

The compressed air supply is checked to insure the air quality is clean, dry, and oil free. Oil mist and moisture on a surface or mixed with the coating can cause premature failure of the system.

To test the air supply for the presence of oil or moisture, a piece of white blotter paper or several layers of cheesecloth are used. The test should be performed at an outlet downstream from the oil or moisture traps and as close as possible to the equipment using the air. Hold the blotter or test material in the air stream for a minimum of 2 minutes. The blotter or test material should be held at a distance of 18 to 24 in. from the source of the air stream being tested. Examine the test material immediately after the test is completed for evidence of contamination by oil or moisture. Examination should be made visually as well as by feeling and smelling the test material. If there is no discoloration on the blotter, the air quality is excellent, while moisture and oil on the blotter indicate unsatisfactory air.

Tests at the blast nozzle should be avoided for safety reasons, but if necessary, make sure that the abrasive source is cut off and that only air is coming out of the nozzle. Allow it to blow for a few minutes to remove any specks of abrasive from the line prior to holding the blotter or test material in front of the nozzle.

If dry air is being discharged in several locations from a common manifold source, it is not necessary to test the air cleanliness at each location. The test should run at each point of use only if more than a hundred feet of air hose is used, or if several distant separate outlet locations are used.

The air supply should be tested at frequent intervals during the day. It should always be tested prior to use and at least once every four hours during continuous compressor operation. When the relative humidity is high, more frequent moisture testing would be in order, since there is more moisture in the air. If compressor operation is interrupted for longer than five minutes (e.g., during breaks or lunchtime), the air supply should be retested prior to use since condensation can form in the air distribution lines.

If oil or moisture is detected in the air stream, compressed air from that source should not be used until the source of contamination is corrected, (i.e., the oil or moisture is removed from the system) and the air stream is retested. Any nozzle blast cleaning done since the last successful test should be thoroughly examined, and if evidence of contamination is evident, the surfaces should be reblasted to specification. Coating or lining materials that have been contaminated or applied over contaminated surfaces require additional inspection prior to acceptance in order to evaluate the possibility of adverse effects. These materials may also have to be removed and new material applied.

To eliminate the source of contamination so that the compressed air supply can be used, there are a number of things a contractor can do. All of these are, however, the responsibility of the contractor and he must correct them.

The source of oil contamination is often the compressor and many times is caused by worn piston rings. Even with good rings, residual amounts of oil will be in the air supply. This can be removed by effective oil and moisture traps installed at a low point in the line between the air receiver and the discharge outlet.

The presence of oil in the air supply may indicate that existing oil and moisture traps are not functioning properly. Clogged filters should be replaced and traps should be continuously bled so they cannot fill up and overflow back into the line. If existing traps are in good working order, and it is not possible to eliminate oil in the air stream, it is possible that the installation of larger or more efficient traps will take care of the problem. In extreme cases, the only practical solution may be to replace or overhaul the compressor. Finally, oilless rotary compressors, while expensive, are available to eliminate the oil problem.

The source of water contamination is the air itself. Air entering the compressor contains varying amounts of water vapor, depending on the prevailing ambient temperature and relative humidity. The saturation point drops as the air is compressed, making the air "wetter." Most of the moisture in the air can be condensed or removed from the air stream by passing the air through an intercooler (i.e., between the first and second stage of the compressor) and aftercooler (i.e., between the second stage and the air receiver). Condensation that occurs after the air leaves the receiver should be removed by moisture traps in the line. Accordingly, the air should be relatively "dry" when it reaches the discharge outlet.

If moisture is detected in the air stream after the compressor reaches operating conditions, it may be due to a malfunction of the moisture traps, and they should be checked in the same manner as suggested for eliminating oil in the air stream. If this does not solve the problem, the intercooler and aftercooler should be checked. Make sure the cooling water is turned on and the drains are not clogged. Increasing the flow of cooling water may improve the efficiency of the intercooler and aftercooler. If these measures do not suffice, the installation of larger or additional moisture traps may solve the problem. Refrigerated air driers, while expensive alternatives, will solve the problem.

Oil and moisture contamination of the coating from the compressed air supply can be very serious, requiring remedial work or even complete removal and replacement of the coating system. For example, adhesion failures, drying problems, soft tacky films, and various other types of defects have been attributed to oil contamination. Moisture contamination can cause such problems as flash rusting of prepared surfaces, spray gun spitting, spatter, fisheyes, bubbles, pinholes, and other film defects.

Determination of Surface Preparation, Cleanliness, and Profile

The primary goals of surface preparation are:

1. To provide a satisfactory, clean surface free of detrimental contaminants.
2. To provide an "anchor pattern" and to increase the steel surface area to improve bonding of the applied coating or lining to steel surface.

Surface preparation is believed to be the most important factor affecting the performance of the coating. Any compromise in surface preparation usually reduces the performance of the applied material as well. Some surface conditions that affect the life of a coating or lining are:

- Oil or grease prevent good coating or lining adhesion and must be completely removed.

AD-A168 486 GUIDE FOR INSPECTION OF COATINGS APPLIED TO HYDRAULIC
STRUCTURES(U) CONSTRUCTION ENGINEERING RESEARCH LAB
(ARMY) CHAMPAIGN IL A BEITELMAN ET AL. APR 86
UNCLASSIFIED CERL-TR-M-86/09 F/G 13/2

GUIDE FOR INSPECTION OF COATINGS APPLIED TO HYDRAULIC
STRUCTURES(U) CONSTRUCTION ENGINEERING RESEARCH LAB
(ARMY) CHAMPAIGN IL A BEITELMAN ET AL. APR 86
CERL-TR-N-86/09 F/G 13/2

2/3

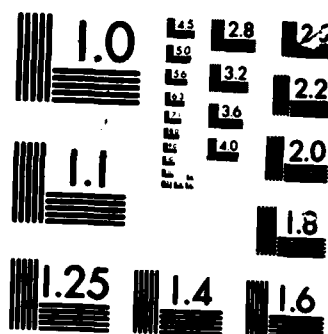
UNCLASSIFIED

CERL-TR-M-86/09

F/G 13/2

U

[illegible]



MICROCOPY

CHART

- Salts of various chemicals may increase moisture permeation through the coating and accelerate the rate at which corrosion will occur.

- Dust and dirt particles on the surface prevent the application of a smooth, uniform film and weaken the adhesion of the coating to the substrate. Debris in the paint can also wick moisture through the film, increasing its permeability and thus decreasing its protective ability.

- Rust cannot be penetrated by most coatings. The result is an uneven film with exposed areas of metal where further corrosion can take place. Rust scale or mill scale also cannot be penetrated, and if painted over will eventually break loose from the substrate taking the coating or lining with it.

- Old paint must be feathered for sound adhesion. Otherwise, it will lift from the surface causing peeling or delamination of the new material. Sharp ridges, burrs, or cuts left in the surface of the metal will prove difficult to coat over to obtain the full thickness and film continuity. They should be removed prior to painting.

The surface preparation standards most universally used in the United States are the Steel Structures Painting Council Standards. Other organizations such as the National Association of Corrosion Engineers (NACE) have also developed surface preparation standards.

The two major criteria involved in the inspection are the degree of cleanliness and the height of the anchor profile.

The Steel Structures Painting Council specification contains the narrative definition of the surface to be obtained under that specification. This narrative definition, together with the pictorial standards contained in SSPC VIS-1, provide the acceptance criteria for the prepared surface (Figure 5-8). The use of SSPC VIS-1 or other visual standards of surface preparation agreed upon by the contracting parties is an option presented in the Appendices to the various SSPC specifications themselves. CW-09940 references only the SSPC specification itself. The Appendices to these specifications are not considered requirements of the specifications.

The degree of cleanliness of the blast-cleaned steel is determined by the use of the definition of the appropriate SSPC standard and by visually comparing the surface with the pictorial standard that represents the specified surface preparation standard for that particular rust grade prior to cleaning.

The various types of abrasive (steel, shot, grit, minerals, slags of various types, etc.) may not provide a blasted surface with the exact color illustrated in the SSPC VIS-1, "Pictorial Surface Preparation Standards." The SSPC visual standards should be used for degree of cleanliness and not color. For example, if specified surface preparation standard was SSPC-SP10, "Near-White Blast Cleaning," pictorial standard A Sa 2-1/2 would be used for Rust Grade A, B Sa 2-1/2 for Rust Grade B, and so forth. Unfortunately, VIS-1 does not address the appearance of previously coated steel. Also, no standards will appear identical to the exact conditions in the field. Because of this, standards prepared at the jobsite are often the best approach. Prior to commencing work, sections of the actual structure to be painted are prepared and agreement reached on the degree of cleaning obtained. The samples can then be sealed in plastic or coated with a clear urethane to serve as a visual reference for the remainder of the project. A detailed discussion regarding the use of these standards is included in Chapter 4.

Areas that do not comply with the degree of cleaning specified should be marked with chalk or aerosol paint (not wax crayons) for reblasting and reinspection. In most cases other defects that are discovered, such as burrs, scabs, slivers, and weld spatter also require removal, and therefore should be marked in the same manner.

The prepared surface should also be visually examined for oil and grease and for dust and loose particles of abrasive residue that were not removed after abrasive blasting. Small bits of grit sometimes cling to the surface by static electricity and are hard to dislodge. In addition to blowing off the surface with compressed air it may be necessary to vacuum the surface to remove residual amounts of dust or to remove small amounts of steel grit. Vacuuming is recommended for removing dust from the inside surface of pipes and vessels and other confined areas.

The surface profile, sometimes referred to as the anchor profile, is a measurement of the surface roughness created by abrasive blast cleaning. The profile is a measurement of the depth of the anchor pattern from the bottom of the valleys to the top of the peaks that have been created. This rough pattern of peaks and valleys increases the area of the steel surface for bonding of the paint. As a general rule, thick coatings require a deeper surface profile than thin coatings. If the profile is too high for the specified coating system, the peaks will project above the coating film, and pinpoint rusting will occur. If the profile is too shallow, poor adhesion can result, particularly for heavier, thicker coatings. It is apparent then, that while the surface profile is an important factor, a minor deviation from the specified profile may or may not be cause for rejection.

Surface profile can be determined by using any of several instruments:

- Surface profile comparators
- Replica tape with a spring micrometer
- Dial surface profile gage.

The Keane-Tator Surface Profile Comparator is the most commonly used surface profile comparator. It consists of a disc with five segments or leaves that are arranged in the shape of a five-pointed star with a hole in the center. Each segment or leaf has been textured to represent a different anchor profile height and has been assigned a number corresponding to the profile height for that particular segment. The discs are high purity nickel electroformed copies of an original which was measured by the Steel Structures painting Council. Different discs are available for measuring the anchor profile of sandblasted (S), gritblasted (G), and shotblasted (SH) steel surfaces.

The numbering system on each leaf of the disc consists of a number, a letter, and then another number. The first number represents the profile depth of that leaf, the letter represents the abrasive used, and the last number represents the year the master disc was formed. Therefore, a profile leaf designated 1S70 represents a 1.0 mil profile with a sand abrasive. The master disc was formed in 1970.

The procedure for using the Keane-Tator Profile Comparator is to place the disc on the surface of the steel and view it through the 5X illuminated magnifier. The magnifier has a magnetic holder for the disc so that it can be held against the surface of the steel and viewed at the same time. Select the segment of the disc that most closely resembles the texture of the blast-cleaned steel surface. The number of the segment coupon indicates the height of the anchor profile. If the anchor profile appears to fall between

two segments or coupons, it should be recorded as such. For example, if the anchor profile is between the 1S70 segment and the 2S70 segment on a Keane-Tator Profile Disc, it should be reported as being between 1 and 2 mils.

Clemtex profile chips are used in essentially the same manner as the Keane-Tator Comparator discs. These are small stainless steel squares onto which the standard profile has been blasted under strictly controlled manufacturing and laboratory conditions.

Testex Press-O-Film Replica Tape, which is measured with a spring micrometer, is about the size of a small adhesive bandage and consists of an emulsion film of microscopic bubbles attached to a noncompressible mylar film backing (Figure 6-1). Replica tape is available in Coarse for profile measurements up to 2.0 mils, and X-Coarse for profile measurements between 1.5 and 4.5 mils.

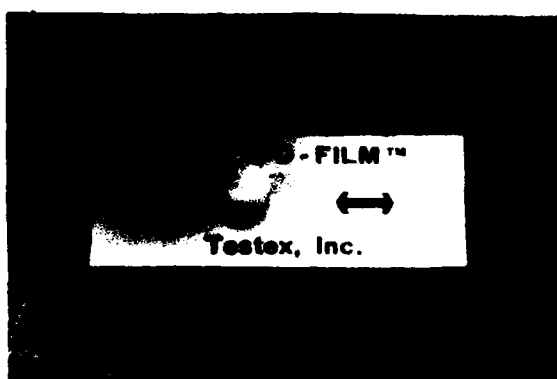


Figure 6-1. Testex Press-O-Film Tape.

To use the tape, remove the paper backing and place the emulsion side of the tape against the surface of the steel. Vigorously rub the area within the circle on the back of the tape with a burnishing tool or other blunt instrument until the surface turns a uniform gray color. Remove the tape and measure the thickness within the circle using the spring micrometer (Figure 6-2). To obtain the height of the anchor profile, deduct 2.0 mils from the micrometer reading to compensate for the thickness of the non-compressible mylar backing.



Figure 6-2. Spring micrometer.

The dial surface gage is essentially a depth micrometer with a direct reading dial. The flat base rests on the peaks of the profile and the pointed probe projects into the valleys. Ten readings are taken in one location and averaged to obtain the profile. It is important not to slide the instrument across the surface to take a reading, otherwise, the projecting pin will become blunted.

Witnessing Coating Mixing and Thinning

Before a coating can be applied to a substrate, it must be suitably mixed to ensure that the material is homogenous. During storage, most coatings tend to show some separation of the lighter and heavier components. Heavier pigments settle to the bottom of the can and sometimes appear as a hard cake, while other materials settle as a soft sludge. Some binders and some paints curdle or gel when stored for too long, a characteristic that shortens the paint's shelf life. Stirring may break the paint down into a homogenous liquid; if not, then the paint must be discarded.

Many coatings form a skin over the liquid surface during storage. If it is possible to carefully cut the skin loose from the side of the can, and if the skin is firm, it may be lifted out in one piece. If the skin is weak and brittle, as much of it as possible should be removed first, then the paint should be stirred and strained through a fine screen or cheesecloth. In all cases, the proper mixing procedure will depend on the type of coating being applied as well as the project specifications. Paint consistency is spoken of in terms of viscosity: a measurement of how fast or how slow a liquid flows. A high viscosity paint is thicker than a low viscosity paint. Proper viscosity is essential for proper application film build and corrosion protection. It is an important factor in selecting the proper equipment for spray application, obtaining good spray atomization properties, and obtaining satisfactory flow and leveling properties. Viscosity of each newly mixed batch of paint should be measured before it is applied.

There are many ways and devices for making viscosity measurements. The most common types found, however, in most paint mixing areas are the Zahn No. 2 and the Ford No. 4 efflux cups. These cups are of essentially the same principle, in that they are used by dipping them into the fluid or filling the cups to their brim and measuring the time it takes the fluid to drain through the orifice in the bottom. In timing, a stopwatch should be used. The watch should be started the instant the flow starts and stopped at the first break evident in the stream. The seconds indicated on the watch indicate the viscosity. For example; if the time was 25 seconds and a No. 4 Ford cup was used, the viscosity would be termed as "25 seconds No. 4 Ford."

The two main things that will effect the change in the viscosity using devices of this nature are the amount of solvent used in the fluid and its temperature. Since its temperature can be a major factor, the temperature must also be indicated; for example, "25 seconds No. 4 Ford at 72° F." The importance of viscosity control lies in being able to reproduce mixtures of solvent and paint every time a new batch is mixed. Viscosity control is just one of the many checkpoints in a finishing system to ensure a consistent quality spray paint application.

Inspection of Application Equipment and Techniques

Spray equipment is classified as either conventional (air atomized) or airless. (The details of the airless and conventional spray equipment are treated at some length in Chapter 5.) A lack of cleanliness is the predominant failure associated with spray guns

and spray pumps. Paint chips or residues of previous coating materials can lodge in the pump, lines, or guns and cause clogging. Cleanliness of mixing equipment, lines, spray pots, guns, tips, and other application equipment is important and necessary.

During application, the operator's safety and respiration equipment should be verified to be in working order. (A detailed discussion of the respiration equipment required on Corps projects is included in Chapter 4.) The spray technique should be reviewed. For example, is the spray gun the proper distance from the work? Is there pattern overlap, uniform speed, triggering before and after each stroke? Is the gun perpendicular to the surface?

Coatings applied too heavily will run or sag. These defects, the result of poor applicator techniques, can often be brushed out before they cure. Any such observations should be reported.

Overspray may also be observed and remedied before the work has progressed too far and costly rework is required. Overspray can be controlled by proper spray application. The presence of loose powdery, partially dry paint material on the coated surface (dry spray) should also be observed. Dry spray can result from excessive spray tip to surface distance, insufficient thinning, or excessive atomization pressure.

A wide variety of coating failures are explored in Chapter 7.

Measurement of Wet Film Thickness

Wet film thickness readings help the painter determine how much material to apply to the surface to achieve the specified dry film. The wet film thickness gage is generally one of two standard configurations: a notch-type (Figure 6-3) or a cylindrical circular dial type.

The notch-type gage consists of two end points on the same plane with progressively deeper notched steps in between. Each step is designated by a number representing the distance in mils or microns between the step and the plane created by the two end points. The instrument is pressed firmly into the wet film down to the



Figure 6-3. Notch-type wet film gage.

substrate and withdrawn. In every case, the two end points will be wetted by the coating material, and in addition, perhaps some of the steps in between. The wet film thickness is considered as being between the last wetted step and the next adjacent higher dry one. If none of the steps or all of the steps in-between the end points are wetted, it is necessary to turn the gage to a different face, as the thickness is outside of that particular range.

When using this instrument, it is necessary to stay away from any surface irregularities that could distort the readings. If determinations are being made on curved surfaces, such as the skin plate of a dam gate, it is important that the gage be used along the length of the curve rather than across its width, as the curve itself could cause irregular wetting of the steps.

The cylindrical thickness gage consists of two outer rings of the same size with an offset inner ring. The instrument is rolled across the surface and withdrawn. The wet film thickness is that point where the coating begins to wet the inner ring.

Wet film thickness gages are of value only if one knows how heavy a wet film to apply. The wet film thickness/dry film thickness ratio is based on knowing the solids by volume of the specific material being measured. The old theory of doubling the desired dry film thickness to establish the wet film to be applied is only correct if the solids by volume of the coating material is 50 percent.

The solids by volume of the coating material is readily available from the coating manufacturer and is commonly included in their product data sheets. The basic formula is **DRY FILM THICKNESS = WET FILM THICKNESS X % SOLIDS BY VOLUME**. A more workable variation of the formula showing the required wet film thickness for the desired dry film thickness is as follows:

$$\text{WET FILM THICKNESS} = \frac{\text{DESIRED DRY FILM THICKNESS}}{\% \text{ SOLIDS BY VOLUME}}$$

The above formulas are accurate provided the solids by volume of the material is not changed. The percentage will change, however, if any thinner is added to the coating. When thinner is added, the total volume of the material is increased without any corresponding increase in the amount of solids. Therefore, the thinned material will result in a lower percentage of solids by volume. Thus, when comparing thinned versus unthinned material to achieve a comparable dry film thickness, a heavier wet film application of the thinned material will be required. To evaluate what the new wet film thickness should be, the new percent solids by volume of the coating material after thinning must be determined. The following formula should be used to determine the required wet film thickness when the material is thinned:

$$\text{WET FILM THICKNESS} = \frac{\text{DESIRED DRY FILM THICKNESS}}{\% \text{ SOLIDS BY VOLUME}}$$

$$100\% + \% \text{ THINNER ADDED}$$

Because the use of the wet film thickness gage is dependent on the solids by volume, and the solids by volume is considered as the "in can" percentage, it is essential that wet film thickness readings be taken as soon as a film is deposited on the surface. Actually, during spray application, between the time the material leaves the gun and

reaches the surface, some of the solvents will already have evaporated, changing the percent of solids by volume slightly. Except for fast-dry coatings such as vinyls and some zinc-rich coatings, this change is not that significant. However, the longer one waits before taking a reading, the less accurate that reading becomes. For highly pigmented coatings (such as zinc-rich), or very fast dry coatings (such as vinyls), wet film thickness readings are so unreliable that they should not be taken.

Determination of Dry Film Thickness

Dry film thickness is measured after the coating is completely dry. Dry film thickness gages for steel surfaces are almost always of the magnetic type. If properly calibrated and operated, they have an error of only approximately 5 to 15 percent at normal temperature (0°-212°F). If the gages are exposed to substantially higher temperatures for extended lengths of time, damage to the magnet and/or plastic probe housing or the gage case itself can result. At sub-zero temperatures, the gage batteries' power output will be altered, springs will contract differently, and the plastic and/or rubber components will embrittle.

Dry film thickness instruments fall into four basic categories: magnetic pull-off, fixed probe, eddy current, and destructive. Each of the four categories will be addressed separately.

Magnetic Pull-Off

The magnetic pull-off type gages include the Mikrotest (Figure 6-4), the Inspector Thickness Gage (Figure 6-5), and the Pencil Pull-Off or Tinsley type gage (Figure 6-6). The Mikrotest and Inspector gages are based on the principle shown in the diagram (Figure 6-7). A lever runs through the center of a scale dial which houses a helical spring. The spring dial is located at the fulcrum point of the lever. One end of the spring is attached to the lever and the other end to the scale dial. One side of the lever contains a permanent magnet while the opposite end contains a counterbalance.

To operate, the scale ring is turned forward and the magnet brought into direct contact with the metal substrate (through the coating or nonmagnetic barrier). Slowly retract the dial, increasing the spring tension which applies a pulling force onto the magnet. Ultimately, the spring tension overcomes the magnet's attraction to the substrate, lifting the magnet from the surface. The spring tension is calibrated so that the point where the magnet breaks contact with the surface can be equated to the distance of the magnet from the surface. This distance is read directly from the scale ring in mils (or microns). The calibrated spring tension is an inverse logarithmic relationship of the distance between the magnet and the substrate (e.g., the greater the spring tension required to remove the magnet, the thinner the coating).

Note that the thickness reading shown on the scale ring when the magnet breaks contact with the surface represents the gap between the magnet and the substrate which is hopefully, but not necessarily, coating thickness. Figure 6-8 shows that three instruments all measure a gap of 5 mils between the magnet and the substrate; however, two of them are including sand, dirt, mill scale, rust, etc. in the total reading; while only the third gage reading is an accurate representation of true coating thickness. Therefore, one must include a thorough visual inspection during the work to assure that the coating is applied over a clean surface that has not become contaminated during drying.



Figure 6-4. Mikrotest magnetic thickness gage.



Figure 6-5. Inspector magnetic thickness gage.

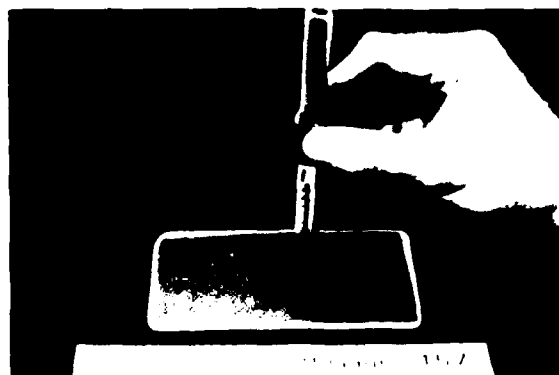


Figure 6-6. Pencil pull-off magnetic thickness gage.

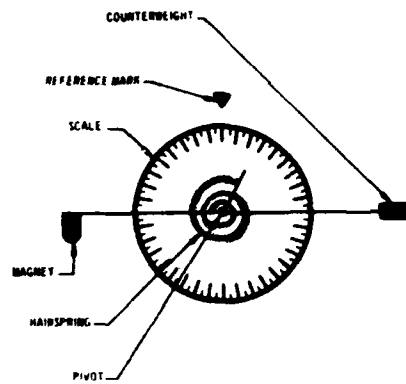


Figure 6-7. Magnetic pull-off gage schematic.

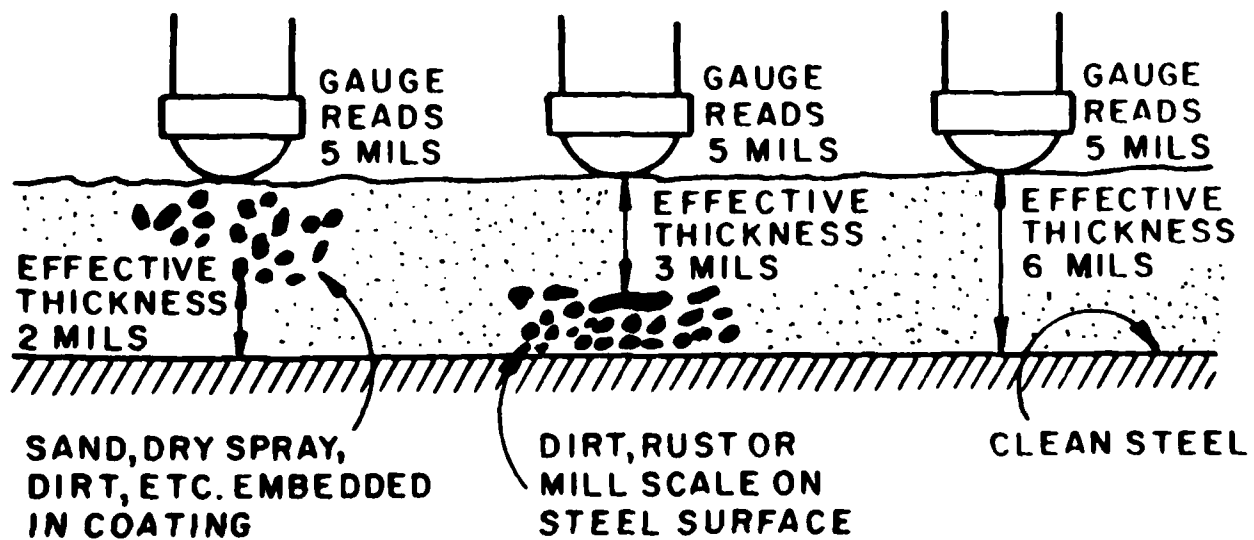


Figure 6-8. Effect of foreign material within paint film.

The Mikrotest and Inspector gages should be calibrated, or at least calibration verified prior to, during, and after each use to assure that they are reading correctly. Calibration methods are described in SSPC-PA2 "Measurement of Dry Paint Thickness with Magnetic Gages," which defines the pull-off instruments as Type I gages. It describes two methods of calibration for the instruments: the "shim" and the plated calibration block techniques. CW-09940 specifies the use of the plastic shim method only. In either case, it is essential that the instrument is calibrated in the desired thickness range of use. If a coating is being measured in the thickness range of 2 to 4 mils, one would not use a gage calibrated at 15 to 20 mils.

As the instrument is based on a logarithmic function and may not be accurate across the entire range, calibration is necessary, requiring the use of either non-magnetic shims (generally plastic or mylar) or calibration test blocks similar to those supplied by the National Bureau of Standards, which are chrome and copper plated steel.

When calibrating using the nonprecision method, verify the shim thickness with a micrometer prior to use. Hold the shim firmly on the bare, cleaned substrate and measure it with the instrument. If the instrument does not read the shim thickness, insert the calibration tool into the slot in the side of the instrument (located at the center of the scale dial), hold firmly, and turn the scale ring until the shim thickness lines up with the hairline. Check the calibration by using shims of lesser and greater thickness to determine the range of accuracy. The instrument is now ready for use for measuring thicknesses within that range over the same substrate and surface preparation. If a section of the bare substrate is unavailable, blast-clean small steel test panels (e.g., 1/8 x 4 x 6 in.) to obtain the same or similar anchor pattern. Protect them from corrosion using dessicant, VPI paper, or other suitable means, and use the panels for calibration.

Calibration using the National Bureau of Standards plates is somewhat different. First, adjust the instrument to read the thicknesses stated on the calibration blocks in the desired range of use. Next, take a gage reading of the bare, uncoated substrate after blast cleaning (or other surface preparation). The instrument will generally read between 0.1 and 0.2 mil up to 1 mil or more over the bare steel. Therefore, any coating thickness readings taken must be corrected by this bare steel base reading in order to determine the coating thickness above the peaks of the profile. Adjust subsequent thickness readings by subtracting the magnetic base reading. For example, if the instrument is calibrated to a 4 mil NBS standard, and a 1/2 mil magnetic base reading on bare blast-cleaned steel is found, a gage thickness reading of 3.5 mils indicates that the true thickness above the peaks is actually only 3 mils.

If one chooses not to physically adjust the instruments as described above, it will be necessary to develop a calibration correction curve using the instrument scale as an arbitrary scale. For example, a 5 on the scale may be equivalent to 3 mils, a 10 equivalent to 7 mils, and so on.

Another type of magnetic pull-off gage is the pencil pull-off gage or Tinsley gage based on a similar principle. Basically, the instrument housing is similar to a large pencil with a magnet at one end. An extension spring is attached to the magnet and to the top of the instrument housing (Figure 6-6). The instrument is held in a perpendicular position and the magnet brought into contact with the substrate. As the housing is lifted, the magnet remains attached to the substrate until the spring tension overcomes the attraction of the magnet, popping it from the surface. The tension on the spring required to lift the magnet is read from the scale in mils or microns. This instrument is not calibrated, although calibration should be verified using either the plastic shim or NBS

method above. In this case, however, a calibration correction curve is necessary if the instrument does not read correctly on the shims. These instruments are not currently approved for use by the Corps.

Some precautions are necessary when using any instrument involving a magnet. First, the magnet is exposed and therefore susceptible to attracting iron filings, steel shot or grit particles, etc. It is important that the magnet be cleaned of any contaminants during use, otherwise the contaminant will incorrectly be read as coating thickness. If the instrument is used on a soft film, allowing the magnet to sink into the surface, a thinner coating thickness will be recorded either because the coating itself may be tacky, holding the magnet beyond the point where the spring should have lifted it from the surface, or alternatively, the coating under the depression caused by the magnet actually will be thinner. In this case, place a plastic shim on top of the coating surface to prevent the magnet from deforming the coating and subtract the shim thickness from any subsequent readings. In addition, any vibrations in the area of instrument use could cause the magnet to be popped from the surface prematurely, giving an erroneously high thickness reading. The instrument should not be used any closer than 1 inch to an edge, and residual magnetism in the structure on which the coating is measured will have an adverse effect on the readings.

The scale dial type instruments have an additional "human error" problem during use. It is easy to continue to turn the dial beyond the point that the magnet has lifted from the surface, giving an incorrect thickness reading. It is imperative that the dial be stopped as soon as the magnet lifts from the surface. Advanced versions of the Mikrotest (Figure 6-9) have addressed this problem by incorporating a mechanism which self-winds and locks the scale dial in place when the magnet breaks contact with the surface.

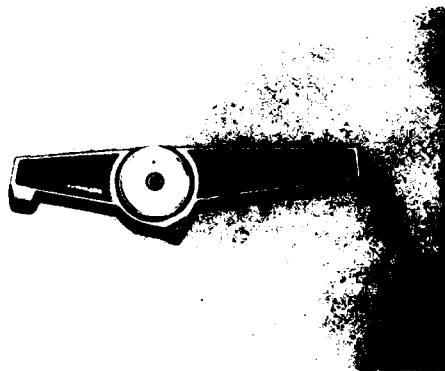


Figure 6-9. Mikrotest IV — advanced version.

Fixed Probe Magnetic Flux Gages

The fixed probe or magnetic flux type gages are described in SSPC-PA2 as Type II gages. They include the Minitector (Figure 6-10), Verimeter (Figure 6-11), GE Gage (Figure 6-12), Elcometer 101 (Figure 6-13), Accuderm, Minitest, Permascope, and others. The Type II gages also must be calibrated prior to use, but calibration is accomplished using the non-magnetic shim method only. The NBS calibration plate method is not suitable for use with these instruments because the calibration plates do not exceed the critical mass of steel needed to satisfy the magnetic field of these instruments.



Figure 6-10. Minitector magnetic thickness gage.

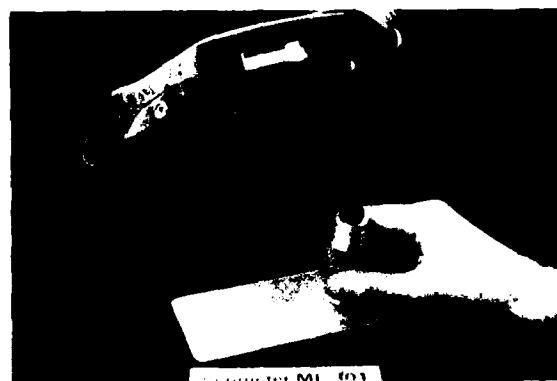


Figure 6-11. Verimeter magnetic thickness gage.



Figure 6-12. GE magnetic thickness gage.

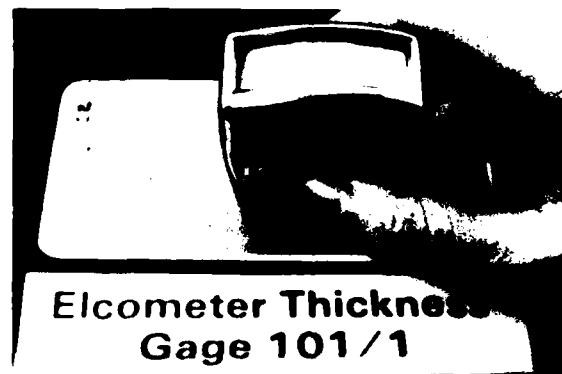


Figure 6-13. Elcometer 101 magnetic thickness gage.

An exception to this "rule" is the Positector (Figure 6-14), which is a Type II gage that can also be calibrated using NBS calibration plates.



Figure 6-14. Positector magnetic thickness gage.

Calibration of the electrically operated instruments (all of the above except the Elcometer 101) is accomplished by placing the instrument probe directly on the bare steel substrate (after surface preparation) and adjusting the designated knob (i.e., "zero") so that the meter reads "0". Next, place the calibration shim of desired thickness on the steel and adjust the appropriate knob (i.e., "adjust," "cal.," etc.) so that the meter indicates the correct shim thickness. Repeat this procedure (zero set, thickness set) until both readings are adjusted correctly. Once again, check the range of calibration by using other shims, both of thinner and heavier thicknesses than that used in the initial calibration. The instrument is now ready for use and will correctly record the thickness of the coating material. Any effect of surface roughness is calibrated into the instrument because it was adjusted over the bare steel, thus eliminating the need for a magnetic base reading correction factor.

Calibration of the Elcometer 101, on the other hand, requires only that the instrument be adjusted to read the thickness of the shim over bare prepared steel, rather than an adjustment of the zero reading and shim reading. Further, it must be recalibrated for each position of use (e.g., horizontal, vertical, and overhead).

The magnetic flux gages have some of the same problems as the pull-off gages related to the tacky films causing the magnet to sink into the surface, the proximity to edges during use (stay at least 1 in. away), and cleanliness of the magnet. In addition, because the instruments are based on flux principles, they are vulnerable to the effect of flux leakage from the instrument to nearby ferrous masses, causing the instrument to be ineffective. Therefore, it is necessary to stay at least 3 in. away from any iron or steel object. Probably the best way to assess the effect of adjacent steel masses or edges is to calibrate the gage in the location where it is to be used. The Corps requires that the gage be calibrated on steel of substantially the same compositional thickness as the coated steel in question. If the coated steel in question is thicker than 1/4 in., a surface at least 1/4 in. in thickness satisfies the minimum mass required by the magnetic field. The probe of these instruments must also be kept perpendicular to the coated substrate during use, otherwise incorrect readings will result.

Eddy Current Gages

Eddy current instruments measure the thickness of nonconductive coatings on nonferrous metal substrates. Included with this type of instrument are the Minitector (Figure 6-10), Minitest (Figure 6-15), Permascope, and others. The probe of these instruments is energized by alternating current, inducing eddy currents in the metal. The eddy currents create opposing alternating magnetic fields within the metal, modifying the electrical characteristics of the probe coil. The extent of these changes is determined by the distance the probe is from the substrate and is shown on a meter as coating thickness. The eddy current instruments are calibrated similarly to the magnetic flux instruments using the plastic shim method.

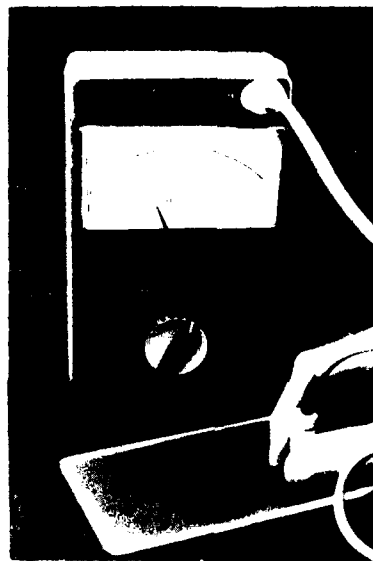


Figure 6-15. Minitest eddy current gage. NOTE: Gage for ferrous substrates is shown. The gage for non-ferrous surfaces is identical.

Destructive Test Instruments

Destructive thickness testing includes the use of the Tooke Gage (Figure 6-16), micrometers, or microscopes. The Tooke Gage consists of a 50X microscope that is used to look at slits in the coating made by precision cutting tips supplied with the instrument. The principle of the Tooke Gage is basic trigonometry. By making a cut through the coating at a known angle and viewing perpendicularly to that cut, the actual coating thickness can be determined from a scale in the eyepiece of the microscope. The instrument can be used for determining the thickness of each coat in multi-coat systems and eliminates many of the drawbacks of the magnetic instruments caused by magnetic fields, proximity to edges, irregular surfaces, magnetic effect of the substrate, profile, etc. The instrument can be used on any substrate (wood, steel, aluminum, concrete, etc.) to measure coating thicknesses up to 50 mils provided the coating is not too brittle or elastic for a smooth cut to be made. A view of a cut through the microscope is shown in Figure 6-17.

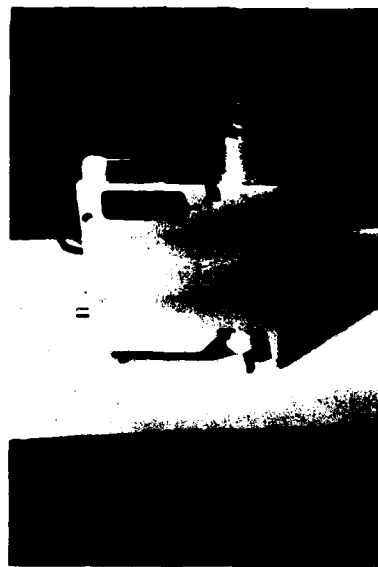


Figure 6-16. Tooke gage.

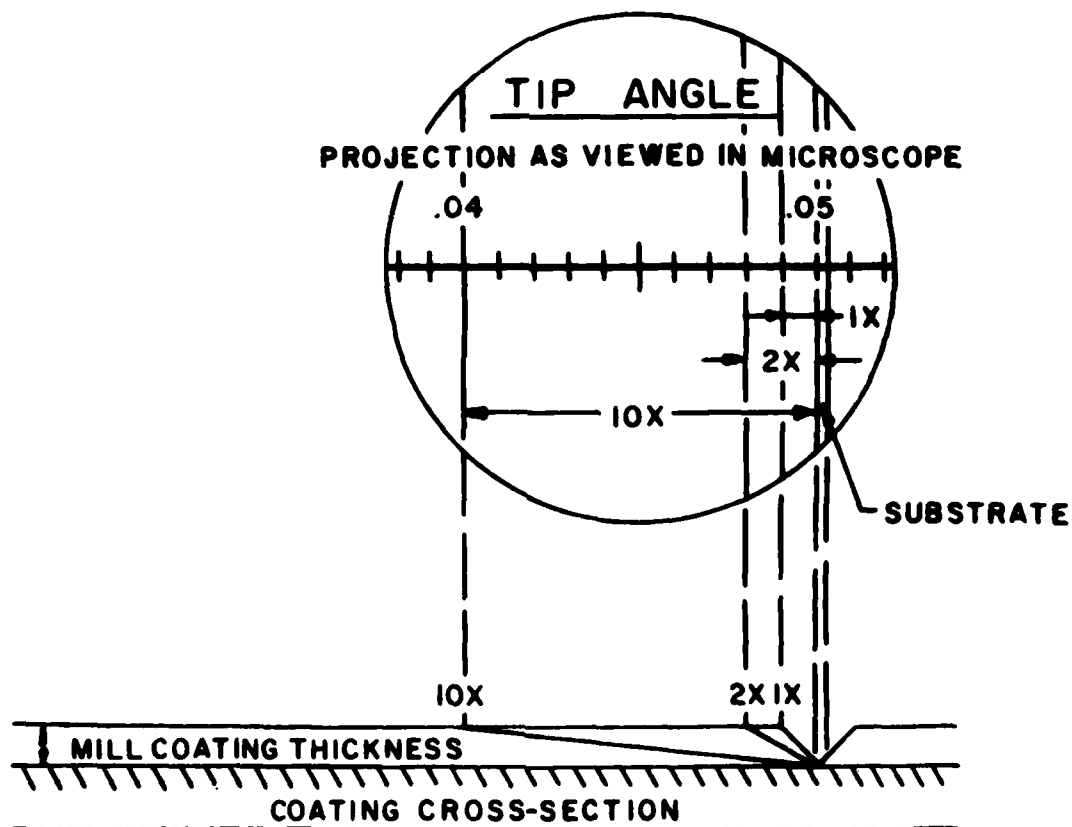


Figure 6-17. Geometry.

Each cutting tip is a different angle and designated as either 1X, 2X, or 10X. The tip used determines the thickness equivalent for each line in the microscope eyepiece. The number of lines corresponding with the coating is divided by the number of the tip used. Therefore, one line when using the 1X tip is equivalent to 1/1 or 1 mil; one line with the 2X tip is 1/2 or 0.5 mil; and one line with the 10X tip is 1/10 or 0.1 mil. Therefore, if the coating cross-section covers seven lines and the 2X tip is used, the thickness is 7/2 or 3.5 mils. Note that "one line" means each small division (e.g., there are 10 "lines" between 0.05 and 0.06).

Another means of destructively measuring the coating thickness is the use of either a depth micrometer or a standard micrometer. The depth micrometer can be used by removing a small section of the coating down to the substrate, permitting the base of the instrument to rest on the coating while the projecting pin is adjusted to the substrate. Alternatively, a sample of the coating can be removed from the substrate and the thickness measured using a standard micrometer. The coating chips could also be returned to a laboratory for microscopic thickness determinations.

General Comments

Thickness readings are taken to provide reasonable assurance that the specified or desired dry film has been applied, but it is impossible to cover every square inch of the surface. SSPC-PA2 states that when using magnetic gages, five separate spot measurements should be made over every 100 sq ft in the area. Each spot measurement consists of an average of three gage readings next to one another. The average of the five spot measurements must be within the specified thickness, while single spot measurements are permitted to be 80 percent of the specified thickness. The single gage readings, however, making up the spot measurement, can underrun by a greater amount. For example, a specification calls for 10 to 12 mils. The five spot measurements (each a cluster of three gage readings) are as follows: Spot 1 (10, 11, 12; average 11); Spot 2 (7, 8, 9; average 8); Spot 3 (12, 12, 12; average 12); Spot 4 (7, 12, 11; average 10); Spot 5 (12, 13, 11; average 12). This measured area would be acceptable because the average of the five spots is 10.6 mils and within specifications. According to SSPC-PA2, the 8 mil spot measurement would be acceptable because "no single spot measurement...shall be less than 80 percent of the specified thickness" (8 mils is exactly 80 percent), and the 7 mil reading is acceptable because "single gage readings...may underrun by a greater amount."

CW-09940 does not specifically adopt the above SSPC-PA2 method. Rather, the Corps defines an average of at least a certain thickness (e.g., System No. 3 average dry film thickness of 6.0 mils) and a minimum thickness at any point criteria (e.g., System No. 3: the thickness at any point shall be not less than 5.0 mils). Further, the Corps defines minimum and maximum dry film thickness per single spray pass or per double spray coat (e.g., System No. 3: "...not more than 2.0 mils (dry film thickness) per double spray coat, nor more than 1.0 mil per single spray pass..."). A combination of methods here would allow the inspector to take a minimum of five readings per 100 sq ft, each consisting of three spot readings close together as outlined above. Instead of applying the SSPC-PA2 thickness limits, however, the Corps minimum can be used.

When one is using magnetic gages to measure multi-coat systems, the average of the first coat must be determined prior to application of the second coat. Readings taken after the second coat is applied will obviously be the total thickness of the two coats combined, and the specific thickness of the second coat can only be estimated by subtracting the average thickness obtained from the first coat reading. The second coat thickness cannot be determined precisely, however, because it is highly unlikely that specific readings taken on the second coat will be over an area of the first coat that is

exactly the first coat average. Therefore, with magnetic gages, it is nearly impossible to specifically determine the thickness of coats applied after the first, and one must rely on average only. If specific second, third, or fourth coat thicknesses are necessary, destructive testing (e.g., Tooke Gage) will be required.

In summary, several factors adversely affect measurement with magnetic gages and these should be taken into account when measurements are made.

1. The character of the steel surface--Rough surfaces from deep blast cleaning will generally result in readings higher than actual paint thicknesses, unless proper allowances are made during calibration as previously described.

2. Steel composition--Use of alloy steel may cause erroneous readings, but differences among most mild, low-carbon steels are insignificant.

3. Thickness of the steel--There is a minimum thickness for each type of gage necessary for accurate measurement.

4. Curvature of steel surfaces--Appreciable curvature may give erroneous readings unless the gage is calibrated on a similar surface or special probes are used with the equipment.

5. Discontinuities--Measurements closer than one inch to edges, corners, holes, etc. may give erroneous measurements unless the gage is calibrated for them.

6. Paint surface condition--Dirt, grease, or other contaminants on the paint surface or gage probe can cause high readings. Tacky paints can cause adhesion of the magnet in pull-off type gages, and soft paints may be indented by gage probes.

7. Orientation of the gage--Holding the gage in a position other than that specified (usually perpendicular to the substrate) can result in erroneous readings, because the gage probe may not properly contact the substrate.

8. Other magnetic fields--Strong magnetic fields such as those from direct current welding or other systems in the area will adversely affect operation of the gage.

Evaluating Cleanliness Between Coats

When a multi-coat system is to be applied, the surface between coats should be examined to be certain that all grease, oil, dirt, bird droppings, pebbles, sand from abrasives, dryspray, and the like have been removed prior to the application of the next layer of coating. Defects in the coated surface which may lead to premature coating failure can be caused by problems of film surface continuity, adhesion to the substrate, and intercoat adhesion, internal mechanical stress damage and abrasion. Many of these defects can be observed visually by a trained inspector.

Pinhole and Holiday Testing

Many coating systems, particularly those for immersion or splash zone service, require additional testing with holiday detectors after the coating has dried.

Pinhole and holiday detectors are three general types: low voltage wet sponge (Figure 6-18), DC high voltage (Figure 6-19), and AC electrostatic type. The basic function of a holiday tester is to detect minute pinholes, holidays, skips or misses in coating systems, all of which can cause premature coating failure.

The low voltage (30 or 67.5 volts are common) wet sponge holiday detectors are used for finding the discontinuities in nonconductive coatings applied to conductive metal bases. Conductive coatings, such as those containing zinc or leafing aluminum cannot be holiday tested in this manner unless they are topcoated with a nonconductive material. The low voltage detector is suitable for use on coatings up to 20 mils thick. The basic unit consists of the detector itself, a ground cable, and a sponge electrode. The ground cable is firmly attached to the bare substrate and the sponge electrode is saturated with tap water. The electrode is moved across the entire surface at a speed of approximately 15 to 20 ft/min, the water permitting a small current to flow through the pinholes down to the substrate. Once the current reaches the substrate, the circuit is completed to the detector unit and an audible signal can be heard, indicating that a pinhole or discontinuity has been found. When coatings are in the range of 10 to 20 mils, a nonsudsing wetting agent (such as Eastman Kodak Photo-Flo) can be added to the water to increase the wetting properties. If the coating system is found to be outside of the 20-mil thickness limits, high voltage holiday detection equipment should be used.

Coatings which are applied at a minimum thickness of 16 mils, such as the Corps of Engineers coal tar epoxy (Systems No. 6 and 6-A-Z) systems should be examined prior to holiday testing for dry film thickness. If the system dry film thickness substantially exceeds the 20-mil range, the coating supplier should be consulted for their recommendations regarding the use of low or high voltage holiday detectors.

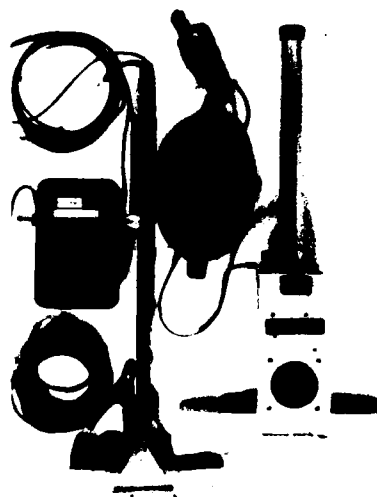


Figure 6-18. Low voltage wet sponge detector.

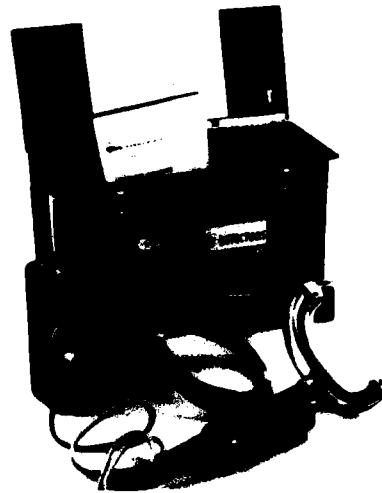


Figure 6-19. DC high voltage detector.

High voltage holiday detectors basically function on the same operating principle as the low voltage described above, except that a sponge is not used. The instrument consists of a testing unit capable of producing various voltage outputs, a ground cable, and an electrode made of conductive neoprene, brass, steel, etc. High voltage units are available up to 20,000 volts and more. The rule of thumb for high voltage detectors is to apply approximately 100 volts per mil of dry film thickness. High voltage detectors are used for nonconductive coatings applied to conductive substrates. Firmly attach the ground wire to a section of the bare substrate and pass the electrode over the entire surface. A spark will jump from the electrode through the air gap down to the substrate at pinholes, holidays, etc., simultaneously detonating a signaling device in the unit.

Since the appropriate voltage for any specific coating is a function of the coating's electrical insulating characteristics (i.e., its dielectric strength) and since this characteristic can be modified by fillers, the guidance of the coating manufacturer must be sought before using a high voltage holiday detector on a particular coating. The application of excessive voltage to a coating can cause a burn through.

For exterior pipeline work, many times the ground wire of the holiday detector is permitted to drag across the earth, provided the pipe itself is grounded to the earth. However, the preferred method of testing is to attach the ground wire directly to the substrate whenever possible.

When testing conductive linings applied over steel substrates (e.g., conductive rubber linings), the AC Tesla Coil type electrostatic testers are generally used. The AC tester has a variable voltage output but does not require the use of a ground wire. The unit constantly emits a corona which is blue in color, but when a break in the lining is passed over, a white spark will jump to the substrate at the holiday or imperfection.

Note that since surface contaminants or dampness may also cause a color change or spark, it is advisable to clean and retest questionable areas to confirm that a break in the lining is present. As the output of this equipment is a pulsed high frequency wave with many high voltage spikes (or transients), this type of equipment should never be used on applied coatings. These transients can cause burn-throughs in the coating. Even when the equipment is used on rubber linings, the electrode should always be kept in motion to prevent localized heat build-up and the resultant burn-throughs.

Test for Adhesion

Occasionally, the adhesion of the coatings has to be tested after application in the field. Different types of adhesion testing methods range from the simple penknife to the more elaborate tensile testing units. The use of a penknife generally requires a subjective evaluation of the coating adhesion based on some previous experience. Generally, one cuts through the coating and probes at it with the knife blade, trying to lift it from the surface to ascertain whether the adhesion is adequate.

A modified version of this type of testing is the cross-cut test, which consists of cutting an "X," or a number of small "squares or diamonds" through the coating down to the substrate. Tape is rubbed vigorously onto the scribes and smartly removed. The cross-hatch pattern is evaluated according to the percentage of square delaminated or remaining intact. The "X" and "cross-cut" tape adhesion tests are described in ASTM D-3359. This so-called knife cross-cut test is a convenient field test which can be used on all Corps of Engineers coatings. It is, however, only semi-quantitative, as some judgments must be made as to what is or is not good enough.

CW-09940 outlines a special laboratory adhesion test for qualifying Corps vinyl formulations. Briefly, the method entails spray application of the various vinyl coatings to White Metal blast-cleaned mild steel test panels. After air drying, the test panels are heat dried at 120° F for 16 hours. Upon cooling, the panels are immersed in warm (85-90° F) tap water for 48 to 72 hours. Upon removal and after being wiped dry, two parallel cuts (at least 1 in. long and 1/4 to 3/8 in. apart) are made through the paint film. A third cut is then made perpendicular to these cuts at the ends. A short section of the film (1/8 to 1/4 in. long) is pried loose with the knife blade. The free end is pulled vertically away from the horizontal panel at the rate of 1/10 in. per second. Paints passing this test shall either break or elongate a minimum of 10 percent.

Tests for Cure

The cure rate of organic coating materials is affected by surface temperature, ambient conditions, coating formulation, and film thickness. Laboratory testing of paint chips is the only true means for verifying cure. Field techniques include the following:

1. Solvent Rub -- On epoxy coatings, use a clean cloth saturated with a strong solvent such as methyl ethyl ketone (MEK) or methyl isobutyl ketone (MIBK) to rub the surface of the coating. If the material is properly mixed and cured, no color will be transferred to the cloth. If the coating is improperly mixed or cured, it will redissolve and the color will be seen on the cloth. Of course, the solvent rub test cannot be used on alkyds and vinyls.

2. Sandpaper Test -- When a properly cured film is abraded with fine sandpaper, a fine powdery residue is observed. Coating material remaining on the face of the sandpaper may indicate an uncured, slightly tacky coating.

3. Hardness Test -- A Barcol hardness tester or pencil hardness tester may be used to check film cure. Such instruments involve exerting a light perpendicular pressure on an instrument which holds a hardened steel indenter ground to microscopic accuracy. The penetration of the spring-loaded indenter is read directly from a scale dial which is divided into 100 graduations. On soft materials, the highest reading attained should be used, since cold flow permits the spring-loaded indenter to continue penetration. Several models of such apparatus are available depending on the relative hardness of the material being tested.

7 COATING FAILURES — CAUSES AND PREVENTION

Coatings are the principal materials for corrosion protection for most steel structures. This is true without regard to the use of the structure, whether it be a dam gate, sheet piling, or steel beam in a building or a bridge. All coating exposures are different from one another, even though the application may appear to be the same, because of different climatic conditions in different areas of the country, and proximity to bodies of water, industrial locations, etc. Since coatings are the primary protection for all of these vastly different exposures, it is understandable that failures on these coated surfaces are inherent, and that time to failure is the critical aspect to be considered.

Failure can occur for a variety of reasons, but generally can be categorized within the following four areas:

1. The improper selection of the coating for the service.
2. Factors inherent in the specific paint material.
3. Application-related deficiencies.
4. Poor structural design.

These common causes of coating failure will be discussed individually below.

Improper Selection of the Coating System for the Service

The primary requirement of the coating system is that it can resist deterioration by the environment in which it is to serve as a protection. No single coating or type of coating is resistant to all conceivable environments. Consequently, many types of coatings have been developed for service under special conditions, and for application by various methods. The selection of a paint among these many types can be made only on the basis of the following factors:

- The known performance of coatings in similar applications.
- The known chemical composition and physical properties of the paint.
- The results of exposures of the coatings under consideration to test environments similar to the conditions of use.

A source of information by which to select a coating is the paint manufacturer or the suppliers of the raw materials that make up the coating material. These sources must be given a detailed, precise description of the conditions under which the coatings will be exposed in order for them to make a satisfactory recommendation.

Paint systems are often combined as a matter of expediency. This can result in costly failures. The compatibility of one coat with another is extremely important to the satisfactory service life of a coating. Generic types of coatings should generally not be mixed unless recommended specifically by the manufacturer, or unless test patch applications have been done to assess compatibility.

Coating Failures Inherent Within the Coating

Chalking

With chalking, the organic binder in the coating tends to gradually disintegrate on the surface, releasing the pigments and allowing them to remain on the surface as a powdery or chalky residue. This is strictly a surface phenomenon. While it can sometimes result in rapid reduction in coating thickness, it is generally a relatively slow process, and one which does not result in catastrophic failure or severe corrosion of the substrate. Chalking or powdering is primarily caused by the action of the ultraviolet rays of the sun on the organic binder. Permanently shaded areas seldom chalk. Humidity and oxygen from the air also play a part in this phenomenon.

The chalking reaction has been used by some manufacturers to produce coatings with self-cleaning properties. When chalking is properly regulated through the prudent selection of the coating binder and the pigments, the chalking reaction can be controlled to the point where the surface erodes very slowly, but at a sufficient rate to keep it free from any grime or dirt which might otherwise accumulate from the atmosphere.

Erosion

Erosion is a type of failure caused by the wearing away of the coating down to the base surface or primer. This wearing away of the surface may be related to the chalking mentioned above. Alternately, it may be aggravated by the surface being exposed to heavy rainfall, hail, wind, or a combination of wind and rain.

Erosion is often seen in brushed coatings where high ridges and brush marks are exposed because of the greater erosion of the raised areas. Erosion of this type can best be prevented by the selection of a chalk-resistant coating, and one which tends to flow out into a smooth film.

Checking

Checking is an age-related failure of a coating. It is characterized by uneven and generally nonlinear, noncontinuous breaks in the coating. These breaks are primarily a surface phenomenon, and do not penetrate the full depth of the coating. Checking can be characterized as visible if the checks can be seen with the naked eye, or microscopic if only seen under magnification.

There are several causes of checking. It is generally a formulation problem which results in surface stresses in the coating. It can occur when solvents evaporate very rapidly from the surface, causing it to shrink more rapidly than the body of the coating. It can also be caused by resins which oxidize on the surface, or by certain pigments which catalyze the checking reaction on the surface. Essentially, checking is a stress set up at the surface which causes the small checks to appear, while the body of the coating is not subject to the same reaction. Expansion and contraction due to heating and cooling and sunlight exposure are also contributing factors.

Cracking

Cracking is an age-related failure caused by conditions similar to those described above under "Checking." In contrast with checking, cracking is not a surface phenomenon, but one in which breaks in the coating penetrate to the substrate. It is a much more damaging failure than checking, since corrosion can rapidly take place.

Cracking occurs in an irregular pattern where the coating stresses are rather uniform. It may be linear or curved, with the cracks meeting and intersecting in a rather typical form. A substrate which can expand and contract can contribute to cracking. Another cause can be excessive thickness of the coating, because of the increased stresses upon curing.

Alligatoring

Alligatoring can be considered a macro-checking failure and is caused by internal stresses set up within the surface of the coating during drying. The stresses cause the coating surface to shrink more rapidly and to a much greater extent than the body of the coating. The strong surface stresses, because of the shrinkage, tend to create very large checks on the surface that do not penetrate to the substrate. An example is an air drying or chemically cured coating applied to a cold substrate. Alligatoring often results upon the application of heat to the coated surface to speed the curing. Such a reaction may be found on coating on the interior of tanks or tank cars. Alligatoring may also be caused by the application of a very strong, hard finish coat over a softer, more pliable primer. In this case, the undercoat flows and moves as the topcoat tends to shrink.

Mudcracking

Mudcracking can be considered a macro-cracking phenomenon where the breaks in the coating usually extend to the substrate. It is a much more catastrophic failure than alligatoring, and can cause immediate corrosion and result in the chipping and flaking of the coating from the surface. It often occurs where coatings are very highly filled, and where they are applied to a surface that dries the coating extremely rapidly. Mudcracking is often a phenomenon of improperly cured inorganic zinc-rich primers. Mudcracking can be prevented by proper formulation to prevent the too rapid drying of these coatings, or by using reinforcing pigments. Mudcracking can also be prevented by the application of thinner films, and by the elimination of runs and sags where curing causes shrinkage stresses that generate this type of failure.

Wrinkling

Wrinkling is the formation of furrows or ridges in the paint system. It occurs when the surface of the paint film expands more rapidly during curing than does the body of the paint and is proportional to the thickness of that surface layer. It is also proportional to the difference between the drying rates and the expansion of the surface layer and the main body of the paint. Normally, coatings are formulated so that the drying process proceeds at the same rate on the surface as in the body. However, when a paint contains an excess of surface driers, the surface of the paint will swell by absorption of oxygen and will wrinkle. Such reactions depend on air temperature, surface temperature, and coating thickness. Excessive thickness aggravates the wrinkling process, since the body of the paint cannot cure sufficiently to resist the change in volume of the paint surface.

Micro-Organism Failure

Both bacteria and fungi can cause coating failure. They primarily attack biodegradable coatings, where the fungus or bacterium derive their energy from the materials making up the coatings. Oil-type coatings, such as alkyds, and coatings using biodegradable plasticizers are most often affected. Fungus attack is reduced or eliminated in oil-type coatings by the addition of zinc oxide, fungicides, bactericides, or a combination of the three to the formulation. In non-oil type coatings, such as epoxies, vinyls, or chlorinated rubbers, plasticizers or modifiers should be nonbiodegradable.

Discoloration

Appearance may be as much a function of coating performance as its corrosion resistance. Coatings that change color after application and become unsightly are considered to have failed. Many of the resins used to formulate coatings contain photosensitive groups, which on exposure to sunlight, cause darkening, yellowing, or other discoloration of the vehicle. Proper pigmentation to shade the basic resin from sunlight is one of the prime methods of preventing discoloration. Often, however, pigmentation is not sufficient. Coatings subject to strong sunlight and weather conditions should preferably be formulated with silicones, acrylics, or aliphatic polyurethanes in order to reduce any possible color charge to a minimum.

Sulfide Discoloration

Sulfide discoloration is characterized by a staining of the film by hydrogen sulfide. Hydrogen sulfide attacks paints containing lead or mercury, turning them gray or black in patches or streaks. Exposure of copper-base, anti-fouling paints to hydrogen sulfide not only turns them black but can inactivate the copper, causing rapid fouling. The use of paints that do not use mercury, lead, or copper pigments, or lead driers is recommended in areas contaminated with hydrogen sulfide.

Pinpoint Rusting

Pinpoint rusting is a consequence of the peaks of the blast profile not being covered. This is a result of inadequate coating thickness being applied, or the proper coating thickness being applied, but the profile being in excess of that required. In any event, the consequence is that the peaks of the profile perforate or stick up through the surface of the film, and when exposed to the environment cause rusting. Pinpoint rusting can also occur at pinholes in the applied film.

Blistering

Blistering is one of the most common forms of adhesion-related coating failure, particularly where the coating is immersed in water or other solutions. It can also occur in areas of high humidity, where there is continuing or intermittent condensation on the surface. Blistering is a consequence of gasses or liquids within or under the coating that exert pressure stronger than both the adhesion and the internal cohesion of the coating (Figure 7-1). This allows the coating to stretch and to form the hemispherical blister. The blister will generally increase in size until the tensile strength of the coating is greater than the internal pressure. If the pressure is greater than the tensile strength, the blister will break. This is often the case where a brittle coating with little extensibility is involved. After the blister breaks, frequently the substrate will be readily attacked, causing rust.

Several forces contribute to the formation of the liquid or gas beneath or within the coating. In addition to the strength of adhesion, the key to most blistering is the moisture vapor transmission (MVT) rate of the coating. Each coating formulation has its characteristic rate, the rate at which molecular water passes through the intermolecular spaces in the coating. Any area of poor adhesion will tend to accumulate moisture vapor at the interface between the coating and the substrate. Moisture vapor in this area creates a vapor pressure that causes blisters to form. Moisture vapor in this area creates a vapor pressure that causes blisters to form. Generally, coatings with the lowest

PAINT BLISTER FORMED BY SOLVENT ENTRAPPED BETWEEN COATS

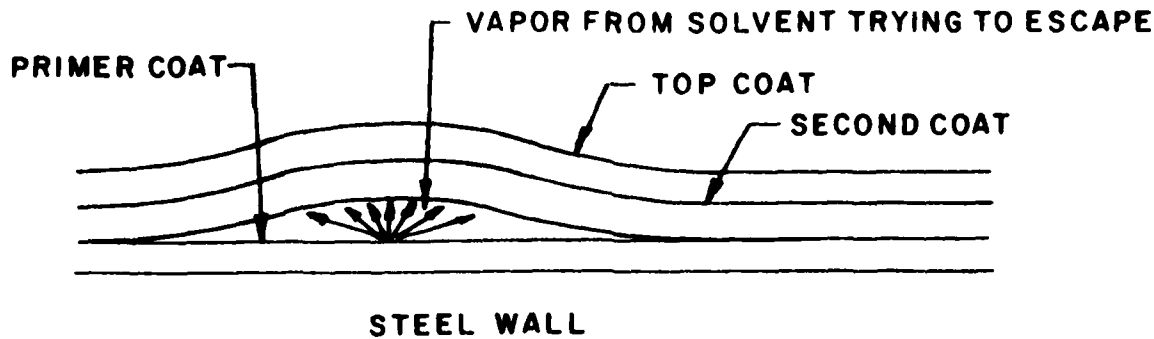


Figure 7-1. Blistering.

moisture vapor transmission rate will have the least tendency to blister. Permeation of moisture vapor is influenced by film thickness, coating pigmentation, and means of application.

Osmosis also contributes strongly to the transmission of water or moisture through a coating. Osmosis occurs when moisture vapor passes through a semipermeable membrane from the water solution having the lesser concentration to the one with higher concentrations of dissolved hydrophilic agent.

Blistering can be a consequence of osmosis generated by materials such as:

- Salt on the surface of the steel beneath the coating.
- Water soluble materials, such as certain pigments (chromates) on the surface beneath the coating.
- The presence of entrapped water-soluble solvents.

In all cases, these materials cause the water to pass through the semi-permeable membrane and lodge against the substrate behind the film. The vapor pressure of the water behind the film exceeds the adhesive force of the coating to the substrate, and blistering results.

Blistering can be prevented by the use of dense, tightly knit coatings with a low MVT rate, and care not to apply the coating over soluble salts (chlorides or chromates, etc.). In addition, coating must be well cured and essentially solvent-free prior to immersion or exposure to high humidity.

Peeling

Peeling is a coating failure usually caused by a coating having a tensile strength greater than its bond strength to the surface. In vinyls, this problem has been overcome by vinyl primers that have superior bond strength when they are applied to clean (preferably abrasive blast cleaned) surfaces. Such coatings bond the vinyl chemically to the substrate. Any coating will peel or pull away from the surface if it has less adhesion to the substrate than tensile strength. Peeling can also occur if the coating reacts adversely with the substrate over a period of time, thus reducing the adhesive strength. Other causes of peeling include application of coatings over surface contaminants such as grease, oil, dirt.

Flaking and Scaling

These two types of failure are adhesion related. Flaking is a term describing the condition where small pieces of the coating detach themselves from the surface of the substrate. Their edges are generally raised up from the surface, and the small pieces can be rather easily removed, leaving the bare substrate. Flaking is quite common on wooden surfaces, and tends to occur after oil paints have oxidized after a period of years. It is a common sight on fences and old wooden buildings. Flaking also occurs on metal surfaces, particularly those which have been galvanized. Oil-type paints which have been applied to galvanized surfaces eventually age and oxidize to the point where the film shrinks enough to pull away from the surface. There could also be an interfacial chemical reaction (saponification), creating a zinc soap between the organic coating and the zinc substrate, which causes loss of adhesion and flaking.

Scaling is similar to flaking, except that the piece that breaks away from the surface is much larger. This is a common type of failure on coated, galvanized surfaces. Pieces of coating several inches in diameter may crack due to aging stresses, curl, and come off in large flakes. Scaling can also occur where a new coat is applied over a very old, well-oxidized coating. The adhesion between the two surfaces is low where surface preparation is poor, and the topcoat, on aging, will tend to curl and to scale. The prevention of flaking and scaling is primarily one of surface preparation.

Intercoat Delamination

This is the failure of one coat to adhere to an underlying coat. The cause is generally within the coating itself. Air reactive coatings, either those that require oxygen or moisture for cure, or coatings that react internally by the action of catalysts or reactive resins are subject to this type of failure. Compatibility of one type of coating to another is essential.

Coal tar epoxy coatings have special problems of intercoat delamination. In addition to the normal internal curing of the coating, external forces can lead to intercoat delamination. Even though the curing of the coating has not progressed to the point of insolubility, if the coating is subject to condensation, rain, or moisture prior to the application of the second coat, intercoat delamination is probable. Also, if the coal tar epoxy solution is applied in the sunlight, even though the coating has not reacted to the point of insolubility, intercoat delamination may occur due to the heat and ultraviolet rays of the sun, causing the surface to cure beyond the point where good adhesion between the two coats can result. Whenever any of the above phenomena occur and the second coat is applied over an insoluble coat, there is a discernible interface between the coats. When water or moisture penetrates to the interface, any apparent

adhesion between the two coats may be lost, causing delamination. Likewise, thermal expansion and contraction by themselves can lead to delamination.

Lacquer-type coatings, such as vinyls and chlorinated rubbers, are not as subject to this type of failure as are the reactive type of coatings, such as epoxies. Lacquer-type coatings are permanently soluble in their own solvents, thus allowing the second coat to somewhat dissolve the first coat, reducing the chance of any interface forming between the two layers.

An additional major cause of intercoat delamination is the contamination of the first coat before the application of the second. Moisture, dust, fumes, chemical fallout, oil, grease, and any contaminants can cause this result. The method of prevention is to prevent the contaminant from reaching the coating during application and/or curing.

Undercutting

Undercutting is another type of adhesion failure that involves the gradual penetration of corrosion underneath the coating from a break or discontinuity in the film, or from an unprotected edge (Figure 7-2). Undercutting often occurs when a coating has been applied over mill scale. Moisture and oxygen penetrate the coating and react with scale, causing it to lose adhesion, and thus form progressive corrosion beneath the coating. The application of coatings over a smooth, dense surface where adhesion is critical also creates a condition inviting this type of failure. Most of these undercutting failures can be substantially reduced by proper surface preparation prior to the application of the coating, and the use of a coating with strong adhesion characteristics.

Application-Related Failures

Application-related failures cause the majority of difficulties encountered with protective coatings of all types. The painting or coating operation is the last item of work on most large projects. The contractor, owner, and engineers are rushing to have the job completed to meet a deadline. This "get the job done fast" philosophy is a cause of many coating failures. There is also a natural tendency to overlook the proper cleanliness and surface preparation that are required for an effective coating job. There are many illustrations where foreign materials of all kinds have been coated over. Most of the defects that occur in applied coatings are unrelated to the coating manufacturer, formulation, or selection of the wrong material, but are "people problems." It has been said that the application job will only be as good as the crew foreman. These problems are caused by a lack of knowledge, training, understanding, and desire to perform, among other factors. Other contributors are lack of proper coating instructions and specifications, and of proper inspection. Care in the writing of application instructions, training of applicators, care in the application itself, and proper inspection of the finished product are crucial for a proper coating application and effective coating performance. Common application-related problems are as follows.

Atmospheric Conditions

Painters normally determine the time of application. The condition of the atmosphere while the paint is being applied and cured can contribute to its success or failure. Paint should be applied during relatively dry conditions. The relative humidity should be 90 percent or less, with the ambient metal or surface temperature at least 5°F above the dewpoint. When the metal temperature is above 100°F, precautions must be taken to make certain that the paint or coating does not dry too rapidly. Many coatings



Figure 7-2. Undercutting.

tend to overspray or surface dry and blister if applied under such circumstances. Temperature is crucial for the cure of many coatings, such as epoxies and coal tar epoxies: because they are internally reactive, they will not cure to a satisfactory coating unless the temperature is proper. Such materials should not be applied at temperatures less than 50°F, except on the recommendation of the manufacturer. Application should be restricted to hours when the temperature is high enough to offset the condensation of moisture during the application and drying periods.

Surface Preparation

The surface preparation requirement is usually specified properly, and on most Corps of Engineers jobs is blast cleaning. However, during the conduct of work, the specified degree of surface cleanliness may not be attained, particularly in the harder-to-reach areas. Additionally, rust-back of properly cleaned surfaces may occur, particularly at dam sites or other areas where moisture and high humidity are present. The occurrence of either deficiency may lead to a lesser protective life of the coating system, and in extreme cases, a premature coating failure.

It is important, after surface preparation, to ensure all spent abrasive dust, dirt, and contamination are thoroughly removed from the cleaned surface to prevent entrapment of contaminants beneath the paint film, and to ensure proper adhesion of the coating.

Mixing

Paint, as supplied by the manufacturer, is usually ready for application by brushing or spraying when received by the applicator. The paint will have been properly formulated to have more than enough durability in the environment intended. For proper application, the paint must be a homogenous mixture, as it was when manufactured. In the mixed state, the consistency of the formulation must be uniform, with the pigments evenly dispersed, since pigments tend to settle to the bottom of the containers during prolonged warehouse storage. Also, the surface of some paints may be covered with a

tough skin. It is essential that paint be carefully remixed before application is attempted. All settled pigment must be redispersed, and any surface skin must be removed. Failure to effect such complete mixing can cause early failure of the paint system.

Thinning

Most manufacturers attempt to provide the liquid coating of the proper consistency to prevent failures related to thinning. Some thinning, however, may still be required. There is no universal thinner for the wide variety of sophisticated coatings that are now used by the Corps of Engineers. Improper thinning can cause many different types of failures. For example, mineral spirits added to solution vinyl coatings will throw the resin out of solution and cause poor adhesion. Improper thinning of an epoxy coating can increase the viscosity rather than reduce it. While thinners are an essential part of any coating, they are incorporated in the manufacture for proper application, proper levelling, and proper drying. Substitution of thinners for those specified should not be undertaken without the written consent of the supplier. Thinners should be added slowly and with constant stirring. Adding a large amount all at once may result in localized overdilution, and may cause curdling of the paint or flocculation of the pigment. This precipitation may appear to stir in, but the portion of the mix that has curdled or flocculated is never restored to its original condition and can cause early failures.

Coating Thickness

A coating is a relatively thin film or barrier separating two reactive materials: the atmosphere on one side and the substrate on the other. This barrier must have an even thickness over the entire surface to be protected, otherwise there will be areas prone to early failure because they are too thin to separate properly the two reactive elements. An excessively thick coating will also cause early failure, due to solvent entrapment or a weakening of its adhesive or cohesive strength. Each coating should have an optimum thickness depending on the surface over which it is applied, and the atmosphere in which it is to operate. This optimum thickness can be determined only by actual experiment or by consulting the manufacturer of the coating.

It is also recognized from a practical standpoint that the coating applicator cannot apply a completely uniform coating, particularly on complicated structures. Coating specifications often give a minimum thickness, such as "The coating shall be applied in two coats to a minimum of 10 mils." Such a specification does not recognize the excess thickness that may result. Some coating types, such as vinyls, are self-limiting because if they are applied too thick, film flaws such as runs, sags, drips, or pinholing may result. The proper specification should recognize the practical aspects of application and provide the applicator with a range of thicknesses which, if followed, will provide the proper average coating thickness for the use intended.

Overspray

Overspray is a major cause of pinpoint rusting on steel surfaces. High performance coatings tend to overspray unless properly applied. Overspray is the adherence of semi-dry coating particles to the surface to be coated. The coating particle dries partially in the air between the spray gun and the surface, and does not flow together with or join other particles to form a continuous film. There are bare or very thin areas between these discrete coating particles. These bare areas act the same as pinholes, and pinpoint rusting results. Because overspray is a function of incorrect spray technique or improper adjustment of the spray equipment, it can occur in any coat from the primer to the final

coat. Existing overspray on surfaces being coated must be removed, or pinhole failure will almost surely occur. At best, an unsightly coating application will result. The dry, adherent particles should be wiped, scraped, or sanded from the surface before a proper wet coat is applied. If the coat applied over existing overspray has already pinholed, the overspray area should be given a wet brush coat to work the coating into existing porous overspray areas.

Pinholes

Pinholing is a common type of application failure caused by any of several factors. The coating formulation itself can cause pinholes, primarily because of the improper solvent balance when solvents evaporate too rapidly at one stage of the drying process. A more common cause is improper application, usually during spraying. The spray gun may be held too close to the surface, be adjusted with excessive atomization pressure, or excessive material pressure may be combined with low atomization pressure. A third cause of pinholes may be the surface itself. The surface may already contain pinholes which are filled with air. As the coating attempts to flow into and displace the air in these surface depressions, a pinhole in the new coating material results as the air escapes. Topcoats with slow drying characteristics or with high solids and solvent content help to alleviate the pinholing. Pinholes are an immediate problem. Once they occur, they will generally persist no matter how many subsequent coats are applied. As one coat is sprayed over another or over pinholes in the substrate, the existing pinholes will act as a reservoir for solvent vapor from the following coat. The vapor pressure in the pinholes will then cause a bubble in the following coat which will eventually break, providing a passage to the original pinhole. Mechanical force is necessary to fill the pinholes with liquid coating. This filling is accomplished by brushing a coat into the pinholed area. Several passes in the same area may be required to fill all pinholes. Pinholes occur most readily in lacquers and solvent drying coatings (such as vinyls). Extra care should be taken during the application of these coatings to prevent pinholes from forming. Some of these materials, such as the vinyl formulations used by the Corps of Engineers, appear to pinhole less if applied by conventional spray rather than airless. This may be because of air entrapment caused by poorly atomized particles splashing onto a wet surface. A slower drying film can flow together longer and thereby fill the pinholes as they attempt to form upon solvent release.

The addition of a small amount of a "slower" (less volatile) solvent to the paint prior to application can further aid in the prevention of pinholing.

Spatter Coating

Spatter coating is caused during the spraying process where the liquid coating particles hit the surface, but the number of particles is insufficient to form a complete and continuous wet film. This is often caused where a painter moves too rapidly, does not sufficiently overlap with each pass of the spray gun, or where he tends to flick the spray gun at a long angle to the surface at the end of a spray pass. The surface may often look as though it is completely coated particularly under poor lighting conditions. Once the coating has been exposed for a short time, however, general pinpoint rusting will be observable. These pinpoints of rust will take place wherever there is an opening between the droplets of the coating. Care in the application process is the solution to this problem. It is necessary to make certain that each pass of the spray gun is overlapped 50 percent with the coating going on as a wet film, that the spray gun is held perpendicular to the surface, and that the gun is not flicked at an angle at the end of the spray pass. Using a cross-hatch pattern during application also helps provide an even, uniform coating.

Holidays

A painter's holiday is anyplace on a surface the painter has missed, such as behind angles, around rivets, boltheads, nuts, or longitudinal areas on pipes. Holidays can be overcome only by care on the part of the painter during application.

Cratering

Cratering is the formation of small, bowl-shaped depressions at a point of contamination on the surface. The craters are caused by the surface tension of the coating being greater than the surface tension of the contaminant. A repelling of the coating away from the point due to a difference in static charge between a particle at that point and of the coating itself will cause a crater. At times, the coating itself may cause the problem, having sufficient surface tension so that the heavy areas of the coating will tend to pull together. Irrespective of the cause, failure of the coating can be expected in the low areas of these craters, usually in the form of pinpoint rusting starting at that point. Once cratering has occurred, the procedure for repairs is to physically roughen the cratered areas by hand sanding or other means, and then apply the coating over the area by brush, coating the bottoms of the craters and thoroughly wetting the surface.

Bleeding

Bleeding is the transfer of a soluble, colored pigment or vehicle in a dried film to a subsequently applied topcoat. It may also be the discoloration caused by the diffusion of soluble ingredients on or in the substrate. To correct this situation, a sealer must be applied.

Blushing

Blushing is the hazing or whitening of the finish as a result of the absorption and retention of moisture formed on the film during or immediately after spraying. It is normally restricted to lacquer-type coatings; however, this blushing does occur on coal-tar epoxy coatings when they are applied or cured during periods of high humidity or if a condensate forms on the coated steel during curing. This leaves an unpleasing streaky, muddy brown appearance, although it does not harm the coating system, unless a topcoat is planned. If a topcoat is to be applied, one of the special surface treatments outlined in Chapter 3 must be performed.

Lifting

Lifting usually occurs when the solvents in the topcoat attack and swell the previously applied film. The result is distortion, blisters, or a wrinkled finish. It may also be caused by wax on the surface, use of an incorrect thinner, poor undercoat drying, or poor adhesion of the old film. To correct, the coating must normally be completely removed. The surfaces must be clean and dry, and one should allow a longer drying time before recoating the undercoat.

Orange Peeling

This is a bumpy pattern similar in appearance to an orange peel. It is inherent in nearly all sprayed films, and is caused by either the spray pattern or the drying characteristics of the finish. It is an appearance problem which should not cause coating

failure. If the degree of orange peel is objectionable, improved flow can be obtained from improved spraying technique, application of a wetter film, or the addition of a small amount of slower solvent to slightly retard drying.

Runs or Sags

Runs are downward movements of a paint film resulting when excess material continues to flow after the surrounding surface has set.

Sags are downward movements of a paint film between the time of application and setting, resulting in a curtain appearance. Both of these are normally caused by too much wet paint.

Design-Related Failures

Many coating failures occur because of the structure design. Unfortunately, most structures are not designed with the application of a protective coating in mind, so many difficult-to-coat areas are built-in during the design phase. Proper selection of coating and careful and proper application can overcome many of the inherent design problems. The following sections discuss typical problem areas.

Back-to-Back Angles

Many structures have trusses, lattice work, and similar areas constructed from angles which are placed back to back. In some instances, the angles are precoated by galvanizing or with inorganic zinc. However, in any severely corrosive environment, even this procedure is prone to failure and extremely difficult to protect properly by the use of coatings. The area between angles is difficult to clean and impossible to coat properly. When such designs exist or where corrosion dictates, the only practical answer is to fill all of the void spaces between the angles with a plastic mastic or caulking compound, and then apply a compatible coating over it. The preferable solution to this problem is to substitute "T" shapes or pipe for these back-to-back angles.

Skip Welding or Stitch Welding

Overlapping plates and roof plates are often stitch welded. The reinforcing ring around the top of a tank may be stitch welded. Angles and similar shapes are stitch welded where a continuous weld is not necessary for joint strength. Stitch welds are almost always an invitation to coating failure, and present very inadequate surfaces for proper coating, even in mild environments. Water and moisture accumulate between the plane surface of the plate. The skip weld does not keep out the moisture. It is almost impossible to obtain a satisfactory corrosion resistant coating in the crevice between skip welds. Corrosion in this crevice proceeds rapidly because of poor drying. Rust buildup can actually force the crevice open and thereby accelerate the corrosion and eventual failure. Caulking or seal welding are frequent solutions to this problem.

Edges

Edges are always a problem on structures using steel shapes, and where the number of lineal feet of edge compared to the plane surface is large. The edges of plates are one of the worst areas because they are sharp. The rounded edges on steel shapes such as I-beams and angles are less of a problem; however, almost invariably where failure occurs on a steel shape, it will be on the edge first. One cause is that many coatings draw thin

on the edges because of surface tension effects. High surface tension of the coating tends to pull it away from the edge, in many cases leaving an extremely thin film at that point. The solution is to apply the coating to edges before applying the overall coating to the structure, a process often referred to as "striping." The edges should then be double-coated with each individual coat. This procedure will help maintain a full coating thickness in these areas.

Welds

Smooth, continuous machine welds present less of a surface preparation and coating problem. Hand welds, in particular, require more care than plane surfaces. These welds are much rougher than machine welds, and may have deep undercuts or pinholes or weld spatter on or around them. Weld spatter in particular--small balls of metal which are spattered away from the weld proper during the welding process--is almost always the focal point of failures. Many times, these balls of metal are lightly adherent and provide not only a protrusion, but mask undercuts as well. Weld spatter must be removed from the surface for a proper coating job. Weld spatter is not always removed by sandblasting. Once the surface is prepared, however, it is a recommended procedure to brushcoat welds, working the coating into all the rough areas before applying the overall coat to the plane surfaces. This aids in preventing premature failure at the weld. When welds are treated in this manner, often the plane surface of coating will fail before the area of the weld.

Inside Corners

Inside corners are on the interior of angles and on the interior of wide-flange beams, and very often at the intersection of planes in built-up members. These inside corners accumulate dust and dirt and, even though the surface may be well-prepared by abrasive blasting, foreign materials accumulate in these areas to a greater degree than on plane surfaces. These materials are often more difficult to remove because of their location. When a coating is applied over dust or dirt in these areas, shrinkage and often cracking of the coating occur, creating an area of immediate failure. Even if these areas are properly cleaned, they often wind up receiving a very heavy coating of the paint, because of double or even triple application during the spraying process. During curing and when shrinkage occurs, the coating may tend to pull away from the interior corner, creating a very thin film or a void beneath the coating. Although the coating may look continuous, it may be exposed to serious corrosive conditions. Alternately, immersion failure may occur because of moisture penetration into this area. To overcome this design problem, apply thin, multiple coats to the inside corners, allowing each coat to dry before the subsequent one.

Discontinuous Areas

Discontinuous areas are located around rivets, boltheads, nuts, threads, and similar areas. The cause of failure is similar to that of sharp edges, crevices, and corners. Careful application is required to eliminate discontinuities in these areas. A brush coat should be applied on all sides and edges of the discontinuity area prior to the application of the overall spray coat.

BIBLIOGRAPHY

- Air Spray Guns*, Training Manual in the Air Spray Training Series, published by Graco, Minneapolis, Minnesota, March 1981.
- Air Spray Manual*, TD10-2, Blinks Manufacturing Company, 1976.
- Coating Types and Characteristics*, published by the Institute of Applied Technology.
- Corrosion Syllabus, *Corrosion/Coating NCEL/NORTHNAVFAC*, Philadelphia, Pennsylvania, March 1984, pp. 19-23.
- Federation Series on Coatings Technology*, Federation of Societies for Paint Technology, Philadelphia, Pennsylvania, 1965 through 1978.
- Fontana, Mars G., and Greene, Norbert D., *Corrosion Engineering*, McGraw-Hill Book Company, New York, 1978.
- Good Painting Practice (Volume 1) and Systems and Specifications (Volume 2)*, Steel Structures Painting Council, Pittsburgh, Pennsylvania, 1982.
- Gross, William F., *Application Manual for Paint and Protective Coatings*, McGraw-Hill Book Company, New York, 1970.
- Hoiberg, Arnold J. (ed.), *Bituminous Materials—Asphalts, Tars, and Pitches, Volume III: Coal Tars and Pitches*, Robert E. Krieger Publishing Company, Huntington, New York, 1979.
- Holl, Charles H., *Inspection and Inspection Instruments*, Kenneth Tator Associates, presented at the 12th Annual Liberty Bell Corrosion Conference, #3, 1974.
- Husock, B., P.E., "Fundamentals of Cathodic Protection," Paper Number HC-2, published by Harco Corporation, Cathodic Protection Division.
- Kline, Eric S., "Coating Application on the Fast Track in the 80s," *American Painting Contractor*, American Paint Journal Company, St. Louis, Missouri, August 1984.
- Kline, Eric S., "Is Total Shop Painting Really the Way to Go?", paper presented at the National Bridge Conference, Pittsburgh, Pennsylvania, 1984.
- Kline, Eric S., "Locking In Coating Savings in Bridge Painting," paper presented at the 3rd World Congress--Coatings Systems for Bridges and Steel Structures, St. Louis, Missouri, 1983.
- Laque, F. L., "Corrosion of Steel-Simplified Theory," *Volume 1--Good Painting Practice*, Chapter 1.1, Steel Structures Painting Council, Pittsburgh, Pennsylvania, 1982.
- Munger, C. G., "Causes and Prevention of Painting Failure," *Volume 1--Good Painting Practice*, Chapter 23.0, Steel Structures Painting Council, Pittsburgh, Pennsylvania, 1982.

- Nuclear Quality Assured Coating Work: A Training Course for Inspectors, Supervisors, Coating Specification Engineers, and QA/QC Personnel*, Institute of Applied Technology.
- Paint and Surface Preparation—A Training Manual for Shipyard Personnel*, U.S. Department of Commerce, Maritime Administration in Cooperation with Avondale Shipyards, Inc., 1979.
- Paints and Protective Coatings Technical Manual No. TM-5-618*, Departments of the Army, Navy, and Air Force, 1969.
- Payne, Henry Fleming, *Organic Coating Technology Volumes I and II*, John Wiley & Sons, New York, 1961.
- Roberts, Aaron Gene, *Organic Coatings—Properties, Selection, and Use*, United States Department of Commerce, National Bureau of Standards, 1968.
- Systems and Specifications, Steel Structures Painting Manual*, Steel Structures Painting Council.
- Tator, Kenneth B., and Trimber, Kenneth A., *Coating (Paint) Inspection Instruments, Types, Uses, and Calibration*, KTA-Tator, Inc., presented at the 21st Liberty Bell Corrosion Course #3, 1983.
- Tator, Kenneth B., and Trimber, Kenneth A., "Inspection," *Volume 1—Good Painting Practice*, Chapter 6, Steel Structures Painting Council, Pittsburgh, Pennsylvania, 1982.
- Tator, Kenneth B., "Engineered Painting Pays Off," *Chemical Engineering*, McGraw-Hill, New York, December 27, 1971.
- Tator, Kenneth B., "How Coatings Protect and Why They Fail," *Materials Performance*, National Association of Corrosion Engineers, November 1978.
- Tator, Kenneth B., "On-The-Job Coatings Inspection Helps Ensure Quality Application," *Materials Performance*, Vol. 10, No. 2, February 1971, pp 30-31.
- Tator, Kenneth B., "Topcoating Zinc-Rich Primers," *Materials Performance*, National Association of Corrosion Engineers, Vol. 15, No. 3, March 1976, pp 9-16.
- Trimber, Kenneth A., and McCartney, Charles A., *The Importance of Coating Application Inspection and Instruments Available for Use*, Kenneth Tator Associates, paper presented at the 14th Annual Liberty Bell Corrosion Course #3, September 1976.
- Uhlig, Herbert H., *Corrosion and Corrosion Control*, John Wiley & Sons, New York, 1971.
- Weismantel, Guy E., *Paint Handbook*, McGraw-Hill Book Company, New York, 1981.
- Weldon, Dwight G., "The Case of the Osmotic Blisters," *American Painting Contractor*, American Paint Journal Company, St. Louis, Missouri, December 1983.

APPENDIX A:

DAILY INSPECTION CHECKLISTS FOR CONCRETE AND STEEL SUBSTRATES

Daily Inspection Checklist for Concrete Substrates

This checklist should be completed when coating operations are performed. Record the item being worked as the general area. Record the specific location within the general area in which work is being performed. Assign a sequential report number. Address only the applicable attributes by checking (✓) the SAT or UNSAT columns. Some items require an entry to be recorded within the "Comment" column; e.g., Method of Surface Preparation. Enter N/A for those which are not applicable; e.g., if first coat is being applied, Recoat Time Observed is not applicable. Any additional comments can be entered in the "Comment" column. The completed checklist is to be signed and dated by the inspector.

DAILY INSPECTION CHECKLIST FOR CONCRETE SURFACES

ITEM _____

REPORT# _____

SPECIFIC LOCATION _____

	(√) SAT	(√) UNSAT	COMMENTS
I. PRE-SURFACE PREPARATION			
1. Concrete Cured			
2. Patching Materials Cured			
3. Form Release Agent (Record)			
4. Curing Compounds (Record)			
5. Grease/Oil Removal			
6. Compressed Air Cleanliness (Record)			
7. Protective Coverings			
II. SURFACE PREPARATION			
8. Method of Preparation (Record)			
9. Size/Type of Abrasive (Record)			
10. Clean/Dry Abrasive			
11. Nozzle Air Pressure (Record)			
12. Dust/Abrasive Removal			
13. Type of Acid (Record)			
14. Rinse After Acid Etch			
15. pH After Rinse (Record)			
16. Visual Appearance			
III. MIXING			
17. Product Name/Mfgr/Batch Numbers (Record)			
18. Clean Equipment			
19. Material Temperature (Record)			
20. Thinner/Ratio (Record)			
21. Time of Mix (Record)			
22. Pot Life (Record)			
IV. APPLICATION			
23. Applicators Name (Record)			
24. Ambient Condition (Record)			
25. Compressed Air Cleanliness (Record)			
26. Protective Coverings			
27. Time Application Began & Surf. Temp. (Record)			
28. Surrounding Air Cleanliness			
29. Recoat Times Observed			
30. Intercoat Cleanliness			
31. Wet Film Thickness (Record)			
32. Type of Application Equip. & Tip Size (Record)			
33. Time Application Complete & Surf. Temp. (Record)			
V. INSPECTION			
34. Visual Appearance			
35. Cure Test			

Signature _____

Date _____

DAILY INSPECTION CHECKLIST FOR STEEL SURFACES

ITEM _____		REPORT# _____	
SPECIFIC LOCATION _____			
		(✓) SAT	(✓) UNSAT
			COMMENTS
I. PRE-SURFACE PREPARATION			
1.	Condition of Edges, Weld Spatter, etc.		
2.	Grease/Oil		
3.	Visible Moisture		
4.	Protective Coverings		
5.	Clean Dry Abrasive		
6.	Recycled Abrasive Test		
7.	Nozzle Air Pressure (Record)		
8.	Compressed Air Cleanliness (Record)		
9.	Ambient Conditions (Record)		
II. SURFACE PREPARATION			
10.	Ambient Conditions (Record)		
11.	Degree of Cleanliness (Record)		
12.	Profile (Record)		
13.	Type and Size Abrasive (Record)		
14.	Dust and Abrasive Removal		
15.	Magnetic Base Reading (Record)		
III. MIXING			
16.	Product Name/Mfgr/Batch Numbers (Record)		
17.	Clean Equipment		
18.	Material Temperature/Potlife (Record)		
19.	Correct Thinner/Amount (Record)		
20.	Time of Mix (Record)		
IV. APPLICATION			
21.	Ambient Conditions (Record)		
22.	Applicator's Name (Record)		
23.	Surface Prep. to Appl. (Record Time)		
24.	Compressed Air Cleanliness		
25.	Protective Coverings		
26.	Time Application Began & Surf. Temp. (Record)		
27.	Surrounding Air Cleanliness		
28.	Recoat Times Observed		
29.	Intercoat Cleanliness		
30.	Proper Pot Agitation		
31.	Type of Application Equip. & Tip Size (Record)		
32.	Time Application Complete & Surf. Temp. (Record)		
V. INSPECTION			
33.	Visual Appearance		
34.	Dry Film Thickness (Record)		
35.	Holiday Test		
36.	Cure Test		

Signature _____

Date _____

Daily Inspection Checklist for Steel Substrates

This checklist should be completed when coating operations are performed. Record the item being worked as the general area (e.g., Pike Island Dam, Gate 2). Record the specific location within the general area in which work is being performed (e.g., upstream skin plate--interior upper level). Assign a sequential report number. Address only the applicable attributes by checking (✓) the SAT or UNSAT columns. Some items require an entry to be recorded within the "Comment" column; e.g., Degree of Cleanliness/Profile. Enter N/A for those which are not applicable; e.g., if first coat is being applied, Recoat Time Observed is not applicable. Any additional comments can be entered in the "Comment" column. The completed checklist is to be signed and dated by the inspector.

APPENDIX B:

INSPECTION PROCEDURES FOR VARIOUS PAINT SYSTEMS

CONTENTS

	Page
Coal Tar Epoxy Systems	B-2
Epoxy-Zinc Rich Systems	B-16
Oil Base Systems	B-30
Vinyl Butyral Wash Primer	B-42
Vinyl Systems	B-50

Coal Tar Epoxy Systems

1.0 Systems and Use

- 1.1 This inspection procedure is applicable to the following coal tar epoxy materials and Corps of Engineers systems:

Coal Tar Epoxy Coatings: C-200 and C-200a

Corps Systems: 6 and 6-A-Z

(Note: System 6-A-Z utilizes either material over 3.0 mils of epoxy zinc-rich E-303b. Application of the epoxy zinc is not covered by this procedure.)

- 1.2 Specific properties and compatibility problems of the coal tar epoxy materials are as follows:
- a. Self-priming, but require clean steel for proper adhesion and performance.
 - b. Can be applied over epoxy zinc-rich E-303b, but not over oil, alkyd, or vinyl coatings.
 - c. Must maintain very stringent recoat times, otherwise special preparation of the coating surface is required for proper adhesion.

2.0 General Requirements for Inspections

- 2.1 Wear proper protective clothing including clean gloves to preclude contamination of the surfaces to be inspected.
- 2.2 Assure that proper lighting and adequate accessibility to areas to be inspected have been provided.
- 2.3 Conduct inspections in a planned and controlled manner in accordance with this inspection plan. Divide large areas into smaller segments to organize structures for proper inspection coverage.
- 2.4 Document the results of all inspections on the Daily Painting Inspection Report Form.
- 2.5 Use inspection instrumentation in accordance with the Use and Calibration of Inspection Instrumentation procedure in Appendix C.

3.0 Continuous Inspections

The following inspections are performed during all phases of the blast-cleaning and painting work, and as such, are termed continuous inspections.

3.1 Protective Coverings

Blast-cleaning dust, abrasives, and paint overspray can damage or impair the operation of certain equipment and structures in the work area. Therefore, protective coverings must be properly installed and remain intact.

3.1.1 Prior to blast cleaning/coating application in a given area, inspect to assure that galvanized, stainless steel surfaces, bearings, gages, previously completed coating work, and any other items designated by the supervisor, have been suitably masked and protected from the coating operations.

3.1.2 Spot-check all masking during work to assure that it remains intact. If the masking is loosened or removed, notify the contractor so that repairs can be made immediately.

3.2 Ambient Conditions

If moisture condenses on a prepared steel surface, corrosion will result prior to the application of the protective coating. Also, moisture condensation on a coating prior to sufficient cross-linking and solvent release can affect its curing. Insufficient or excessive air and surface temperatures during application can lead to the entrapment of solvents or the formation of a dry paint film that does not knit and flow together properly. Therefore, it is important to monitor the ambient conditions during all work.

3.2.1 Monitor the ambient conditions and surface temperatures approximately every 4 hours during surface preparation and coating application (or more frequently if extremes are being approached). Use a psychrometer and surface temperature thermometer in the general location of the areas being worked.

3.2.2 The surface temperature should be at least 5°F higher than the dew point temperature during final surface preparation or coating application in order to eliminate the possibility of moisture condensation.

3.2.3 The relative humidity should be less than 90% during surface preparation or coating application in order to eliminate condensation problems.

3.2.4 There are no limits on the surface and ambient temperatures for surface preparation. However, for application, the temperatures must be 50°F or above.

3.2.5 Work should not be performed in the fog, rain, or snow.

3.3 Compressed Air Cleanliness

The cleanliness of the compressed air is important to assure that moisture or oil is not deposited onto the surface during blast cleaning, blow down, or when using conventional air spray. Moisture in the air supply can cause flash rusting on the steel or blistering of the coatings. Oil contamination will not allow the coal tar epoxy coating to adhere to the clean steel.

3.3.1 Test the compressed air to be used for blast cleaning, blow down, and conventional spray application to assure that it is free from moisture and oil. At a minimum, test the air supply every 4 hours for every compressor system in operation.

3.3.2 Determine air cleanliness downstream of moisture and oil separators. Hold a clean white piece of blotter paper approximately 18 in. from the air supply for 1 to 2 minutes. If, at the end of that time, no moisture or discoloration is visible on the blotter paper, the air is acceptable.

3.3.3 If the air is unacceptable, all quality-related work using the compressed air system found to be contaminated should be halted. Inspect the work completed between the last "good" test and the unacceptable one for signs of damage due to moisture or oil contamination. When the lines are cleaned, repeat the test before work resumes.

4.0 Surface Preparation

4.1 Equipment and Surroundings

Assure that the "Continuous Inspection" items of Section 3.0 are satisfactory (protective coverings, air cleanliness, ambient conditions) and examine the blast equipment for safety. The blast nozzles must be equipped with operating "dead man" controls which will shut off the abrasive flow if the nozzle is dropped. The hose sections must be connected using external couplings that are locked together with wires. The blasters must be supplied with air-fed hoods that comply with MESA and air purity requirements. Other personnel in the blasting area must use dust masks.

4.2 Sharp Edges and Weld Spatter

Sharp edges and weld spatter are detrimental to coating performance as the coating will draw thin on these areas and provide insufficient protection. In addition, weld spatter can become dislodged in service, removing the coating with it.

4.2.1 Inspect for the removal of sharp edges, weld spatter, and laminations to the extent necessary to provide a surface suitable to receive protective coatings. This generally necessitates the removal of all weld spatter and the rounding of edges to a radius of approximately 1/16 to 1/8 in. Welds need not be ground smooth or flush.

4.2.2 Report any questionable areas to a supervisor for resolution. This includes the presence of pits with sharp edges.

4.3 Grease and Oil

Deposits of grease or oil on the surface must be removed prior to preparation so that they are not impacted into the surface or spread onto areas which have already been prepared. The presence of grease or oil will interfere with the adhesion of the coating.

4.3.1 Prior to blast cleaning inspect for any deposits of grease or oil. If found, such deposits shall be solvent cleaned in accordance with SSPC-SP1. Solvent cleaning requires the frequent use of new clean cloths and clean solvent to assure that the contaminant is removed, rather than simply spread across the surface.

4.3.2 After cleaning, visually reinspect the areas to ensure that the grease and oil have been removed.

4.4 Nozzle Pressure

Adequate blast pressure at the nozzle is important for productivity. The optimum blasting pressure at the nozzle is 90 to 100 psig. If the pressure drops to 60 psig, productivity is decreased by 50%. Excessive pressures can also be detrimental as the abrasive may be fractured prior to reaching the surface, eliminating its effectiveness. In addition, excessive pressures can lead to greater operator fatigue. Note that the blasting pressure has a greater impact on productivity than quality as the same degree of surface cleanliness and roughness (profile) can be achieved with lesser pressures.

4.4.1 During the initial start-up of the job, record the pressure of the air used for blast cleaning. Take the pressure as close to the blast nozzle as possible using a hypodermic needle pressure gage. Insert the needle through the hose in the direction of the nozzle and record the reading with abrasive flowing. When taking a reading, all nozzles as well as other pneumatic equipment associated with the compressor system should be operating.

4.4.2 This reading need only be taken at the beginning of a project or when changes are made in the compressed air system.

4.5 Abrasive Cleanliness/Profile

Clean, dry abrasive is essential for achieving quality work. An oily abrasive will contaminate the surface and a damp abrasive will clog blast pots in addition to creating flash rusting.

The surface roughness or profile of the steel after blast cleaning is also important in that it assures proper adhesion of the coating system. An insufficient profile can lead to peeling or disbonding of the coating system, while an excessively heavy or deep profile can result in pinpoint rusting caused by peaks of the steel extending through the coating system. The surface profile after blast cleaning should normally range from 1.5 to 3.0 mils. This roughness can generally be accomplished by a medium/fine mesh sand. Note that steel abrasives will have a tendency to create a much rougher, irregular profile and cause "hackles" or sharp projections of steel on the surface which will significantly reduce the effective thickness of the coal tar epoxy system at that point. Such hackles can lead to pinpoint rusting. Note also soft abrasives may "powder" upon impacting the surface and as such become a weak contaminant that can affect coating adhesion. Soft abrasives may also contain clay which can lead to blistering of the coating in immersion service.

4.5.1 Visually check the abrasive for dryness and contaminants. If the abrasive is damp or contains numerous particles other than the abrasive material itself, it should not be used.

4.5.2 Measure and record the surface profile of the blast cleaned steel using the Keane-Tator Surface Profile Comparator or Testex Press-O-Film tape. Each measurement is the average of three profile readings within an area of 1 square foot. Record the profile for every 500 square feet of surface area.

4.5.3 At least twice daily visually verify that the abrasive gradation is correct. At the beginning of the job, retain a sample of the abrasive that

provides the proper surface profile and use it as a standard of comparison. If samples taken in the field appear to be smaller or larger than the control sample or if the surface profile changes report the discrepancy to a supervisor.

- 4.5.4 If abrasive is recycled, make certain that it is a steel abrasive or other type which is capable of recycling. Sand shall not be reused. Inspect a sample of the abrasive for oil and grease contamination a minimum of twice daily. Drop a handful of the recycled abrasive into a vial of water (approximately 1 pint) and shake vigorously. The abrasive should not be used if oil is visible on the surface of the water.

4.6 Surface Cleanliness - Steel

A high degree of surface cleanliness is necessary for the proper adhesion and performance of coal tar epoxy systems. Rust, mill scale, old paint, grease, or oil will interfere with the adhesion and performance of the systems. Touching the steel with bare hands can also affect paint performance as the oils and salts from the skin can cause blistering if painted over. Greasy, oily gloves must also not be allowed to contact the cleaned surface.

- 4.6.1 The surfaces shall be blast cleaned to a degree of cleanliness "approaching White Metal." In order to determine compliance with this degree of cleaning, mentally divide the structure into squares approximately 6 inches on a side. Seventy-five percent of the squares shall be free of all rust, mill scale, or staining (e.g. White Metal). The remaining 25% of the squares are permitted to contain very slight shadows, stains, or discolorations resulting from very thin, adherent, sparsely scattered residues of mill scale or corrosion products. However, on surface irregularities such as edges, interior angles, welds, rivet lines, junctions of joining members, and pits, the White Metal grade of cleaning shall be strictly enforced.
- 4.6.2 Inspect 100% of the cleaned surface for compliance with the above and pay particular attention to rivet heads, backside of angles, and inaccessible areas as these are historically the most poorly prepared. If necessary, use a mirror to view these areas.
- 4.6.3 Inspect with the unaided eye. However, a five power hand magnifier may be used as required to verify surface cleanliness.
- 4.6.4 Inspect the surface from various angles to assure that the angle of incidence of the profile is not hiding areas of rust or mill scale or alternatively, that shadows caused solely from the angle of profile are not rejected.
- 4.6.5 During the inspection, reexamine the surface for the presence of sharp edges, weld spatter, or additional laminations uncovered by abrasive blasting. If present, report them immediately to a supervisor for resolution.
- 4.6.6 Mark areas for rework that are not in conformance with the specification requirements. Use only those marking devices agreed upon or permitted

by the specification or supervisors (i.e., chalk). Do not use wax crayons as the coal tar epoxy will not adhere to the wax in the event it is not completely removed during the rework.

- 4.6.7 Reinspect the deficient areas after rework for specification compliance. In addition, spot check previously acceptable areas to assure that flash rusting has not occurred. Continue to mark and reinspect deficient areas until the surface is within specification requirements. Record the final condition of the surface.

4.7 Surface Preparation - Concrete

The preparation of concrete for the application of coatings is as critical as the preparation of steel. Loose, powdery, or damp concrete, incompatible membrane curing compounds, or a smooth concrete surface will lead to disbonding of the coal tar epoxy.

- 4.7.1 Verify that new concrete surfaces have been permitted to age for a minimum of 30 days prior to painting, otherwise the moisture content in the concrete can interfere with the curing of the coating.
- 4.7.2 If curing compounds have been used, make certain that they are of a type compatible with the coal tar epoxy. If the type of curing compound is unknown or it is incompatible, verify that it has been completely removed by mechanical means.
- 4.7.3 Inspect the surface for freedom from grease or oil. If present, it can be removed by solvent and/or detergent cleaning in accordance with SSPC-SPI.
- 4.7.4 Inspect the surface for freedom from loosely adherent material such as dirt, dust, laitance, efflorescence, bleed water residues, and so forth. If present, they can be removed by wire or fiber brushing, scraping, light sand blasting, or other similar mechanical means. Note that blast cleaning of interior walls and floors shall be restricted to wet or vacuum type.
- 4.7.5 Surface glaze will interfere with the adhesion of the coating. If a glaze is present, it can be removed by light blast cleaning or scrubbing with a 5% solution of phosphoric acid. The phosphoric acid treatment must be followed by rinsing the surfaces with water to neutralize.
- 4.7.6 Additional roughening requirements are necessary for poured floors to ensure proper adhesion. Verify that floors have been prepared by acid etching or blast cleaning in order to clean the surface and provide the necessary tooth. The texture of the surface after preparation shall be roughly equivalent to that of an 80-120 grit sandpaper. If the acid has no effect on the surface, painting must not proceed. This indicates that grease, oil, concrete hardeners, membrane curing compound, or other similar interference materials are present. Report this situation to a supervisor for resolution.

If acid etching is used, the surface shall be thoroughly rinsed with clean water to remove all traces of the acid. After rinsing, the pH should be

neutral or slightly alkaline (7-8). pH may be measured using pH indicating paper (e.g., alkacid test ribbon, A-979, Fisher Scientific, Pittsburgh, Pennsylvania). If it registers below 7, additional washing with an alkaline solution (e.g. TSP in water) followed by a fresh water rinse is necessary.

4.7.7 Verify that the concrete is dry prior to painting. Determine this visually at the time of application and in advance by taping 2 ft x 2 ft squares of polyethylene to the bare concrete at random locations. Allow the patches to remain in place overnight. Any traces of moisture beneath the polyethylene the following day indicates that too much moisture is present.

4.7.8 Report the presence of voids, fins, and other defects to a supervisor prior to painting, as sacking or other preparation may be required.

4.8 Cleanliness Prior to Coating

The cleaned steel and concrete must be dust-free and in the case of steel, free from corrosion prior to coating application, otherwise the benefits of such thorough preparation are lost. Such interference material will impair coating adhesion and can serve to wick moisture through the coating directly to the substrate.

4.8.1 Inspect the surfaces prior to coating application to assure that abrasive residues have been removed and that the surface is free from dirt, dust, or other debris. Pay specific attention to corners and inaccessible areas for pockets of abrasive that may remain. In addition, be certain that the scaffolding has been thoroughly blown down to remove pockets of dust or abrasive which could be dislodged during the coating operation. The dust cleanliness at this point is even more critical if airless spray is to be employed, since the airless gun cannot be used to blow down the surface prior to application, as is the case with a conventional gun.

4.8.2 The prepared steel surface shall be painted within 8 hours after cleaning and prior to the formation of flash rusting. During the cleanliness inspection, pay special attention to assure that flash rusting has not occurred. If present, mark for removal or to be isolated from painting. If isolated from painting, assure that the areas are recleaned and painted at a later time. The recleaning shall involve blast cleaning, as power tools tend to polish the surface, providing an unacceptable smoothness for adhesion of the coal tar epoxy coating.

5.0 Mixing and Thinning

Mixing - Thorough mixing of the coal tar epoxy materials is essential to assure that pigments and solids have not settled out into the bottom of the container(s) and that a homogenous blend results. Mixing of the correct ratio of the components is mandatory; otherwise proper chemical cross-linking and curing will not result.

Thinning - The amount of thinner to be added depends on the temperature at the time of application. Generally, more thinner is added at higher temperatures because as the temperatures increase, the speed at which the thinners evaporate also increases. Thus, it can be difficult to apply a continuous wet film due to such

rapid evaporation. In such cases, additional thinning is necessary. Conversely, less thinner is used at lower temperatures to decrease the "wet time" and reduce the possibility of runs, sags, and solvent entrapment. In any event, the coating must be fluid enough to flow through the hoses and must be atomized properly so that a smooth continuous film can be applied.

- 5.1 Assure that adequate ventilation is present in the mixing area. If natural ventilation is inadequate to prevent fire and explosion hazards, local exhaust ventilation must be provided. Such ventilation must be capable of providing 100 feet per minute of air flow.
- 5.2 All mixing buckets and paddles must be clean of old paint and debris. Otherwise, the new paint can become contaminated.
- 5.3 Inspect the material delivered to the mixing site for coating type and condition of cans. Leaky containers should be rejected and reported to a supervisor as they indicate potential problems.
- 5.4 Material which has exceeded its shelf life should be segregated from use and reported to a supervisor. The shelf life of coal tar epoxy materials is generally 1 year. Older material is most likely satisfactory; however, samples must be sent to the USA-CERL laboratory for recertification prior to use.
- 5.5 Record the batch numbers of the material and determine the liquid temperature with an immersion thermometer. Both Parts A and B must be a minimum of 55°F prior to mixing in order to ensure that the chemical cross-linking will occur.
- 5.6 Observe and record the mixing and thinning procedures and amounts. The mixing ratios are as follows: C-200a is 4 parts of Part A (base) to 1 part of Part B (catalyst) by volume. The mixing ratio for C-200 is 3-1/2 parts of Part A (base) to 1 part of Part B (catalyst) by volume.

Component A must be thoroughly mixed before adding Component B. After the two components are combined, a heavy-duty mechanical stirrer must be used until a smooth homogenous mixture results. At that time, up to one pint per gallon xylene may be added. If air pollution regulations do not permit the use of xylene, an approved replacement can be used. After mixing, inspect the bottom of the containers to ensure that no settlement is remaining.

- 5.7 The pot life of both formulations decreases as the temperature increases; and conversely, it increases as the temperature decreases. Pot life ends when the coating material loses body and begins to sag during application. The pot life of the material at various temperatures is as follows:

55°F	- 8 hours
60°F	- 6 hours
75°F	- 4 hours
100°F	- 1 hour

Note: pot life commences at the time Components A and B are combined.

6.0 Application Equipment

- 6.1 Coal tar epoxy paint can be applied by brush, roller, or spray. Conventional spray is *preferred* over airless as airless has a tendency to overbuild the film thickness, thus producing runs, sags, and drips, particularly in areas containing complex shapes, as the volume of material expelled by the airless gun is difficult to control.
- 6.2 Record the type of application equipment used including the manufacturer, identification of tips, needles, nozzles, hose sizes and lengths, roller nap length, and so forth.
- 6.3 The following spray equipment is suitable for the application of the coal tar epoxy, although equivalent equipment can be substituted. The application equipment shall be kept clean and in good mechanical condition.

Conventional Spray

Spray gun: industrial quality gun such as Binks 18 or 62 or DeVilbiss P-MBC or JGA.

Fluid tip: large enough orifice to allow passage of the material without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Suitable tips with an orifice in the 0.090 in. range are Binks 67 or DeVilbiss D.

Air cap: sized with sufficient air openings to atomize the paint stream without causing excessive solvent evaporation prior to deposition of the paint film. Suitable caps are Binks 67PB or DeVilbiss 64.

Air hose: 5/16 in. ID provides the proper volume of air.

Material hose: 1/2 in. ID allows for the proper feed of the material. Smaller hoses create too great a restriction, while larger hoses allow too much material to flow.

Hose lengths: less than 150 ft is preferred, with 50 ft to 100 ft common. The hoses should be as short as possible.

Atomization: only enough air pressure to atomize the paint without creating dryspray; usually around 80 psi at the gun.

Spray pot: the spray pot must be equipped with a bottom feed.

Airless Spray

Airless spray is permitted for use on broad, simply configured surfaces. Note that the use of conventional spray is strongly recommended for the coal tar epoxy systems. This is because the use of airless spray makes it difficult to control thickness in complex areas. Much of this can be avoided by the use of conventional spray because of better controls on the gun.

Spray gun: industrial quality spray guns such as Binks 520 and Graco 207-300.

Spray tip: large enough orifice to allow passage of solids without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Note that reversible tips are very helpful because of the speed with which clogs can be removed, and adjustable tips are beneficial for complex structures. This allows for the immediate changing of the spray pattern size (by changing the orifice size) at the spray gun. The smallest orifice diameter provides the best atomization because the volume of paint is being forced through a smaller opening. The orifice size for coal tar epoxy paints is generally kept to approximately 0.031 in.

Alternatively, there are "ball tips" available which combine two separate tips of the same orifice with different fan widths on the same ball. These tips provide a narrow fan for small surfaces and a wide fan for larger surfaces. Fan width tip combinations range from 2-4 in./6-8 in. up to 2-4 in./16-18 in.

Pump: Binks Jupiter 8D and Graco Bulldog 30:1 (Teflon packings recommended).

Fluid pressure: Binks >2400 psi and Graco >2400 psi.

Air line pressure: Binks 70-90 psi and Graco 70-90 psi.

7.0 Application

7.1 Ventilation/Safety - When painting in enclosed spaces, sufficient exhaust ventilation shall be provided to exchange the air with fresh air at a rate of 5000 CFM for each spray gun in operation.

7.1.1 Make periodic tests to assure that the vapors are not accumulating and that the enclosed spaces are safe from fire and explosion hazards. Use a calibrated explosimeter or organic vapor analyzer.

7.1.2 Verify that the spray painters and other personnel in the work area are wearing air-fed hoods or cartridge-type respirators suitable for use with coal tar epoxy coatings.

7.2 Ambient Conditions - The coal tar epoxy coatings should be applied only when the surface and ambient air temperatures are 50°F or above, and it can be reasonably anticipated that the average ambient temperature will be 50°F or higher for the five-day period following the application; otherwise proper curing will not occur. At the time of application, the surface temperature should be at least 5°F greater than the dew point temperature in order to prevent the formation of condensation on the surface.

7.2.1 Monitor the ambient conditions with a sling psychrometer and surface temperature thermometer every four hours, or more frequently if extremes are being encountered.

7.2.2 Verify that the air temperatures are between 50°F and 100°F, the surface temperature is at least 5°F greater than the ambient dew point temperature, and the relative humidity is less than 90 percent.

7.3 Brush/Roller Technique - Brush and roller application shall be carried out with a stiff bristled brush or long nap roller heavily laden with material. Both must be used in such a manner to spread out the coating quickly and smoothly without excessive strokes. Whenever possible, the second series of brush or roller strokes should be made at right angles to the first to provide uniformity in thickness and complete coverage.

7.4 Spray Technique

7.4.1 Verify that standard good spray techniques are being used:

- a. The spray gun must be held perpendicular to the surface at all times as arcing will create erratic thicknesses and overspray.
- b. The gun-to-surface distance should be held constant (6 to 10 in. for conventional and 12 to 16 in. for airless) to avoid too heavy or dry a coat.
- c. The trigger should be released at the end of each pass to avoid excessive film build.

7.4.2 Single Spray Coat - Verify that each coat of the coal tar epoxy materials is applied as a single spray coat. This operation (per coat) consists of a preliminary extra pass on edges, corners, angles, seams, crevices, weld lines, and similar surface irregularities. Such irregularities shall be sprayed from every direction in order to assure complete coverage of all surfaces. After the preliminary spray pass, the paint shall be applied using a 50 percent overlap per pass. Subsequent coats or passes should be applied at right angles to the first wherever possible to provide uniformity in coverage and thickness.

7.5 Thickness and Coverage

The coverage rate of the material is approximately 110 square feet per gallon for each 8 to 10 mil coat.

System No. 6 (coal tar epoxy only) must be applied in a minimum of two coats to provide a total dry film thickness or not less than 16 mils *at any point*. Additional coats are to be applied as required to achieve the minimum 16 mil requirement.

System 6-A-Z (zinc-rich primer/coal tar epoxy) - The epoxy zinc-rich paint must have been applied to an average dry film thickness of 3.0 mils (absolute minimum of 2.5 mils *at any point*). The coal tar epoxy must be applied in a minimum of two coats to achieve a total dry film thickness of 16 mils minimum *at any point* in the system.

7.6 Time Between Coats

The finish coating of the epoxy zinc primer (System 6-A-Z) must be accomplished within a rigid time frame. The coal tar epoxy does not have the ability to "bite" into an overcured epoxy zinc-rich paint. Likewise, the time between coats of the coal tar epoxy is also critical. Exceeding the times will not allow for proper adhesion without special treatment of the paint surface.

- 7.6.1 If the epoxy zinc-rich paint (System 6-A-Z) has cured longer than 96 hours, verify that it is completely recoated with an additional thin tack coat of the same zinc-rich paint prior to application of the coal tar epoxy. The coal tar epoxy should then be applied within 6 to 96 hours later.
- 7.6.2 Verify that the coal tar epoxy is recoated with itself within the very stringent recoat times, as shown below; otherwise special surface preparation is required.

Maximum Recoat Times

50°F	72 hours 60°F	36 hours
75°F	18 hours 90°F	8 hours

Note that under the most extreme conditions involving high temperature and sunlight, the drying time between coats shall not exceed 8 hours, and the reduction of this interval to a few hours or less is strongly encouraged.

- 7.6.3 If the above coal tar epoxy drying times have been exceeded, or the existing undercoat develops a brown surface discoloration (caused by moisture or condensation soon after application), verify that one of the following treatments has been performed prior to application of the next coat.
- The coating surface has been etched slightly by hand sanding or brush blasting, using fine sand, low air pressure, and a blast nozzle-to-surface distance of approximately 3 feet.
 - The brown discoloration has been removed and/or the surface of the coating softened by wiping with clean cloths dampened with N,N-Dimethyl Formamide solvent or with Koppers Company, Inc. Bitumastic 2CB solvent. The solvents may be applied to the surface by spraying a light fog followed by wiping. Solvent puddles are not permitted and must be removed immediately after formation. The subsequent coat must be applied in not less than 15 minutes or more than 3 hours after solvent treatment.
 - Combination of both.

8.0 Inspection of Each Coat

It is important to examine each coat prior to application of the next for film thickness and cleanliness. Insufficient film thicknesses per coat can lead to pinpoint rusting prior to application of the next due to the presence of exposed peaks of the surface profile. Excessive film builds per coat can result in solvent entrapment and the formation of pinholes, both of which increase the moisture permeability of the paint system. Dirt or debris trapped within or between coats can lead to poor adhesion and blistering in service. Debris projecting through the film can serve to wick water through the coating directly to or close to the substrate.

- 8.1 Do not inspect the surface until the coating has sufficiently dried and cured to the degree that it can support handling without damage.
- 8.2 Inspect for surface dirt or debris prior to the application of subsequent coats. If present, it must be removed. Verify that the recoat times of Section 7.6 have not been exceeded, or if so, that the proper steps outlined in that section have been taken.
- 8.3 Report the presence of pinpoint rusting to a supervisor for resolution. Minor localized areas may be repaired by hand-sanding followed by application of the material. Larger areas may require complete blast cleaning.
- 8.4 Inspect the coating thickness using a nondestructive magnetic dry film thickness gage.

8.4.1 Perform only a cursory thickness inspection between coats in order to minimize the time spent on the coating and to avoid unnecessary contamination. Note that if the coal tar epoxy is soft or tacky, it will not be possible to obtain a reasonably accurate measurement as the instrument probe will deform the coating or "stick" during pull-off type measurements (e.g., Mikrotest). Therefore, if it is necessary to measure the thickness at a time when the coal tar epoxy is still slightly soft, a plastic shim of known thickness can be placed between the instrument magnet and the coal tar epoxy paint. By subtracting the thickness of the shim from the total measurement, a reasonably accurate assessment of the coating thickness can be made.

8.4.2 For the inspection of the complete system, take a minimum of 15 readings per 100 square feet of large, flat surfaces. The 15 readings should be made in five clusters of three readings each. Each cluster should cover a few square inches.

The number of readings on complex surfaces shall be significantly greater than those above for large, flat surfaces. All locations of all complex surfaces must be measured as these are the areas that historically fail first due to insufficient or excessive paint coverage. The specific number of readings is dependent upon the results obtained. Initially, a minimum of three readings for every 4 to 5 square feet should be made. If the readings continue to be satisfactory, the frequency can be reduced; if unsatisfactory, the frequency shall be increased.

The minimum total system thickness of any single point shall not be less than 16 mils.

8.4.3 Report the presence of insufficient or excessive film thickness to a supervisor. Insufficient thickness can generally be corrected by applying an additional coat to the deficient areas. The resolution of excessive film thickness depends on the continuity of the film. This can be determined by using a razor blade to shave away the coating and examining for the presence of voids; and by probing the coating to determine its adhesion. If voids, pinholes, or poor adhesion are detected, partial or complete coating removal may be required.

8.5 Visually inspect each coat and the final system for runs, sags, holidays, pinholes, and overspray/dryspray. Note that the purpose of the coal tar epoxy paint is for protection, and therefore a void-free film is necessary. Runs or sags which do not contain pinholes or voids normally need not be removed.

8.5.1 A holiday detector may be useful in the final system inspection for the presence of holidays, excessively thin areas (e.g., on edges), voids, and pinholes.

8.5.2 The use of the holiday detector is described in detail in Appendix C, but basically it utilizes a wetted sponge electrode which is grounded to the surface through the detection unit. The sponge is passed across the surface and the water penetrates pinholes or flaws in the coating system to complete a circuit. A bell or buzzer rings each time a flaw is encountered.

8.6 Mark all defective areas for repair using chalk or a marker designated by a supervisor. Reinspect the reworked areas in accordance with this procedure to assure final specification compliance.

9.0 Curing Prior to Service

Monitor the ambient conditions after application of the final coat to assure that the material is properly cured prior to service, otherwise blistering will occur. A minimum of 7 days of curing at average temperatures of 75° and above are necessary. For average temperatures between 50° and 75°F, 10 days are necessary. For colder temperatures, consult a supervisor.

9.1 Since drying times prior to placing the structure in service are computed from the day the final coat is applied to a given area, it is desirable to apply the total system to a given area prior to moving on to the next. Area-by-area completion will also facilitate the adherence of the applicator to the strict recoat times given in 7.6.2.

9.2 Since it is difficult to verify that complete curing has occurred, even after 7 days of ambient drying, it is recommended that areas subject to immersion or particularly abrasive action on a structure be cleaned and totally coated first in the sequence of work. This will permit these "high wear" areas to have the greatest dry time prior to service.

10.0 Record Keeping

It is crucial to be certain that all painting records (see Daily Inspection Checklist) are properly recorded and filed for each project. The painting record is the only written verification of what was actually done at the time. If questions arise later, the records will be the only source of information or clues as to the material, equipment, and atmospheric conditions at the time of surface preparation, coating application, and cure.

Epoxy Zinc-Rich Systems

1.0 Systems and Use

- 1.1 This inspection procedure is applicable to the following epoxy materials and Corps of Engineers systems:**

Epoxy Zinc-Rich Coating: E-303

Corps Systems: 6-A-Z, 21-A-Z
(Note: System 6-A-Z uses the epoxy zinc-rich with either C-200 or C-200a coal tar epoxy; System 21-A-Z uses the epoxy zinc-rich primer with an epoxy topcoat(s) per MIL-P-14441. Application of the coal tar epoxy and epoxy are not covered by this procedure.)

- 1.2 Specific properties and compatibility problems with the E-303 epoxy zinc-rich material are as follows:**

- a. Used as primer only.**
- b. Generally requires clean steel for proper adhesion and performance. It will lift vinyl and oil-base materials.**
- c. Must maintain very stringent recoat time, otherwise special preparation of the coating surface is required for topcoating.**

2.0 General Requirements for Inspections

- 2.1 Wear proper protective clothing including clean gloves to prevent contaminating the surfaces to be inspected.**
- 2.2 Assure that proper lighting and adequate accessibility to areas to be inspected have been provided.**
- 2.3 Conduct inspections in a planned and controlled manner in accordance with this inspection plan. Divide large areas into smaller segments to organize structures for proper inspection coverage.**
- 2.4 Document the results of all inspections on the Daily Painting Inspection Report Form.**
- 2.5 Use inspection instrumentation in accordance with the Use and Calibration of Inspection Instrumentation procedure in Appendix C.**

3.0 Continuous Inspections

The following inspections are performed during all phases of the blast cleaning and painting work, and as such, are termed continuous inspections.

3.1 Protective Coverings

Blast-cleaning dust, abrasives, and paint overspray can damage or impair the operation of certain equipment and structures in the work area. Therefore, protective coverings must be properly installed and remain intact.

3.1.1 Prior to blast cleaning/coating application in a given area, inspect to assure that galvanized, stainless steel surfaces, bearings, gages, previously completed coating work, and any other items designated by the supervisor, have been suitably masked and protected from the coating operations.

3.1.2 Spot-check all masking during work to assure that it remains intact. If the masking is loosened or removed, notify the contractor so that repairs can be made immediately.

3.2 Ambient Conditions

If moisture condenses on a prepared steel surface, corrosion will result prior to the application of the protective coating. Also, moisture condensation on a coating prior to sufficient solvent release can affect its curing. Insufficient or excessive air and surface temperatures during application can lead to the entrapment of solvents or the formation of a dry paint film that does not knit and flow together properly. Therefore, it is important to monitor the ambient conditions during all work.

3.2.1 Monitor the ambient conditions and surface temperatures approximately every 4 hours during surface preparation and coating application (or more frequently if extremes are being approached). Use a psychrometer and surface temperature thermometer in the general location of the areas being worked.

3.2.2 The surface temperature should be at least 5°F higher than the dew point temperature during final surface preparation or coating application to eliminate the possibility of moisture condensation.

3.2.3 The relative humidity should be less than 90 percent during surface preparation or coating application to eliminate condensation problems.

3.2.4 There are no limits on the surface and ambient temperatures for surface preparation. However, for application, the temperatures must be between 50°F to 125°F, and preferably between 50°F to 100°F.

3.2.5 Work should not be performed in the fog, rain, or snow.

3.3 Compressed Air Cleanliness

The cleanliness of the compressed air is important to assure that moisture or oil is not deposited onto the surface during blast cleaning, blow down, or when using conventional air spray. Moisture in the air supply can cause flash rusting on the steel or blistering of the coatings. Oil contamination will not allow the epoxy zinc-rich coating to adhere to the clean steel and will also create craters or fisheyes in the applied film.

- 3.3.1** Test the compressed air to be used for blast cleaning, blow down, and conventional spray application to assure that it is free from moisture and oil. At a minimum, test the air supply every 4 hours for every compressor system in operation.
- 3.3.2** Determine air cleanliness downstream of moisture and oil separators. Hold a clean white piece of blotter paper approximately 18 in. from the air supply for 1 to 2 minutes. If, at the end of that time, no moisture or discoloration is visible on the blotter paper, the air is acceptable.
- 3.3.3** If the air is unacceptable, all quality-related work using the compressed air system found to be contaminated should be halted. Inspect the work completed between the last "good" test and the unacceptable one for signs of damage due to moisture or oil contamination. When the lines are cleaned, repeat the test before work resumes.

4.0 Surface Preparation

4.1 Equipment and Surroundings

Assure that the "Continuous Inspection" items of Section 3.0 are satisfactory (protective coverings, air cleanliness, ambient conditions) and examine the blast equipment for safety. The blast nozzles must be equipped with operating "dead man" controls which will shut off the abrasive flow in the event the nozzle is dropped. The hose sections must be connected using external couplings that are locked together with wires. The blasters must be supplied with air-fed hoods that comply with MESA and air purity requirements. Other personnel in the blasting area must use dust masks.

4.2 Sharp Edges and Weld Spatter

Sharp edges and weld spatter are detrimental to coating performance as the coating will draw thin on these areas to provide insufficient protection. In addition, weld spatter can become dislodged in service removing the coating with it.

- 4.2.1** Inspect for the removal of sharp edges, weld spatter, and laminations to the extent necessary to provide a surface suitable to receive protective coatings. This generally necessitates the removal of all weld spatter and the rounding of edges to a radius of approximately 1/16 to 1/8 in. Welds need not be ground smooth or flush.
- 4.2.2** Report any questionable areas to a supervisor for resolution. This includes the presence of pits with sharp edges.

4.3 Grease and Oil

Deposits of grease or oil on the surface must be removed prior to preparation so that they are not impacted into the surface or spread onto areas which have already been prepared. Grease or oil will interfere with the adhesion of the coating.

4.3.1 Prior to blast cleaning, inspect for any deposits of grease or oil. If found, such deposits shall be solvent cleaned in accordance with SSPC-SPI. Solvent cleaning requires the frequent use of new clean cloths and clean solvent to assure that the contaminant is removed, rather than simply spread across the surface.

4.3.2 After cleaning, visually reinspect the areas to ensure that the grease and oil have been removed.

4.4 Nozzle Pressure

Adequate blast pressure at the nozzle is important for productivity. The optimum blasting pressure at the nozzle is 90 to 100 psig. If the pressure drops to 60 psig, productivity is decreased by 50 percent. Excessive pressures can also be detrimental as the abrasive may be fractured prior to reaching the surface, eliminating its effectiveness. In addition, excessive pressures can lead to greater operator fatigue. Note that the blasting pressure has a greater impact on productivity than quality as the same degree of surface cleanliness and roughness (profile) can be achieved with lesser pressures.

4.4.1 During the initial start-up of the job, record the pressure of the air used for blast cleaning. Take the pressure as close to the blast nozzle as possible using a hypodermic needle pressure gage. Insert the needle through the hose in the direction of the nozzle and record the reading with abrasive flowing. When taking a reading, all nozzles as well as other pneumatic equipment associated with the compressor system should be operating.

4.4.2 This reading need only be taken at the beginning of a project or when changes are made in the compressed air system.

4.5 Abrasive Cleanliness/Profile

Clean, dry abrasive is essential for achieving quality work. An oily abrasive will contaminate the surface and a damp abrasive will clog blast pots in addition to creating flash rusting.

The surface roughness or profile of the steel after blast cleaning is also important in that it assures proper adhesion of the coating system. An insufficient profile can lead to peeling or disbonding of the coating system, while an excessively heavy or deep profile can result in pinpoint rusting caused by peaks of the steel extending through the coating system. The surface profile after blast cleaning should normally range from 1.0 to 3.0 mils. This roughness can generally be accomplished by a medium/fine mesh sand. Note that steel abrasives have a tendency to create a much rougher, irregular profile and cause "hackles" or sharp projections of steel on the surface which are difficult to properly coat with a thin film epoxy zinc-rich primer. Such hackles can lead to

pinpoint rusting. Note also soft abrasives may "powder" upon impacting the surface and as such become a weak contaminant that affects coating adhesion. Soft abrasives may also contain clay which can lead to blistering of the coating in immersion service.

- 4.5.1 Visually check the abrasive for dryness and contaminants. If the abrasive is damp or contains numerous particles other than the abrasive material itself, it should not be used.
- 4.5.2 Measure and record the surface profile of the blast-cleaned steel using the Keane-Tator Surface Profile Comparator or Testex Press-O-Film tape. Each measurement is the average of three profile readings within an area of 1 square foot. Record the profile for every 500 square feet of surface area.
- 4.5.3 At least twice daily visually verify that the abrasive gradation is correct. At the beginning of the job, retain a sample of the abrasive that provides the proper surface profile and use it as a standard of comparison. If samples taken in the field appear to be smaller or larger than the control sample or if the surface profile changes, report the discrepancy to a supervisor.
- 4.5.4 If abrasive is recycled, make certain that it is a steel abrasive or other type which is capable of recycling. Sand shall not be reused. Inspect a sample of the abrasive for oil and grease contamination a minimum of twice daily. Drop a handful of the recycled abrasive into a vial of water (approximately 1 pint) and shake vigorously. The abrasive should not be used if oil is visible on the surface of the water.

4.6 Surface Cleanliness - System 6-A-Z (Epoxy Zinc-Rich/Coal Tar Epoxy)

When using System 6-A-Z, the degree of surface preparation required must "approach White Metal" because the removal of rust, mill scale, old paint, grease, and oil is necessary for the proper adhesion and performance of this system. Touching the steel with bare hands can also affect paint performance as the oils and salts from the skin can cause blistering if painted over. Greasy, oily gloves must also not be allowed to contact the cleaned surface.

- 4.6.1 To determine compliance with the "approaching White Metal" degree of cleaning, mentally divide the structure into squares approximately 6 inches on a side. Seventy-five percent of the squares shall be free of all rust, mill scale, or staining (e.g., White Metal). The remaining 25% of the squares are permitted to contain very slight shadows, stains, or discolorations resulting from very thin, adherent, sparsely scattered residues of mill scale or corrosion products. However, on surface irregularities such as edges, interior angles, welds, rivet lines, junctions of joining members and pits, the White Metal grade of cleaning shall be strictly enforced.

- 4.6.2 Inspect 100 percent of the cleaned surface for compliance with the above and pay particular attention to rivet heads, backside of angles, and inaccessible areas as these are historically the most poorly prepared. If necessary, use a mirror to view these areas.
- 4.6.3 Inspect with the unaided eye. However, a five-power hand magnifier may be used as required to verify surface cleanliness.
- 4.6.4 Inspect the surface from various angles to assure that the angle of incidence of the profile is not hiding areas of rust or mill scale or alternatively, that shadows caused solely from the angle of profile are not rejected.
- 4.6.5 During the inspection, reexamine the surface for the presence of sharp edges, weld spatter, or additional laminations uncovered by abrasive blasting. If present, report them immediately to a supervisor for resolution.
- 4.6.6 Mark areas for rework that are not in conformance with the specification requirements. Use only those marking devices agreed upon or permitted by the specification or supervisors (i.e., chalk). Do not use wax crayons, as the epoxy zinc-rich will not adhere to the wax in the event it is not completely removed during the rework.
- 4.6.7 Reinspect the deficient areas after rework for specification compliance. In addition, spot check previously acceptable areas to assure that flash rusting has not occurred. Continue to mark and reinspect deficient areas until the surface is within specification requirements. Record the final condition of the surface.

4.7 Surface Cleanliness - System 21-A-Z (Epoxy Zinc-Rich/Epoxy)

The preparation for System 21-A-Z will vary from power tool cleaning to a degree "approaching White Metal" depending on the structure being coated and its service environment. The description and inspection requirements for "approaching White Metal" are shown in Section 4.6 of this procedure. The requirements for power tool cleaning and brush-off blast cleaning are shown below.

- 4.7.1 Power Tool Cleaning - Power tool cleaning shall conform with SSPC-SP3, which requires the removal of loose mill scale, loose rust, and loose paint with power wire brushes, power impact tools, power grinders, power sanders, or by a combination of these methods. It is not intended that all mill scale, rust, and paint be removed by this process; but loose mill scale, loose rust, loose paint, and other detrimental foreign matter shall be removed. Residues are considered to be tight if they cannot be removed by probing the edge with a dull putty knife.

When preparation of the overall surface is carried out by the power tool method, the welds and adjacent areas shall be cleaned thoroughly of flux, rust, and other interference material. After preparation of the welds, brush scrubbing and rinsing with clean water is also required to essentially remove all soluble deposits. Wetting the surfaces during water-washing operations shall be limited to the weld area required to be

treated, and such areas shall be recleaned (by power tools) prior to painting to assure that flash rusting is not present. This washing step can be eliminated only if the original power tool cleaning is carried out with such thoroughness as to assure that all deposits (soluble or otherwise) have been removed (e.g., "Bright Metal").

- 4.7.2 **Brush-Off Blast Cleaning** - This grade of cleaning is generally used for ferrous surfaces that are subjected to exterior or interior atmospheric exposure. A brush-off blast-cleaned surface finish is defined as one from which all oil, grease, dirt, rust scale, loose mill scale, loose rust and loose paint or coatings are removed completely, but tight mill scale and tightly-adhered rust, paint, and coatings are permitted to remain provided that all mill scale and rust have been exposed to the abrasive blast pattern sufficiently to expose numerous flecks of the underlying metal fairly uniformly distributed over the entire surface. Remaining material is considered to be tight if it cannot be lifted when probing the edges with a dull putty knife.

When a brush-off blast is employed, the welds and adjacent surfaces shall be cleaned thoroughly to an SSPC-SP6 "Commercial Blast" cleanliness and will be considered adequately prepared provided that weld spatter not dislodged by the blast stream is removed with impact or grinding tools.

4.8 Cleanliness Prior to Coating

The cleaned steel must be dust-free and free from flash rusting prior to coating application, otherwise the benefits of such thorough cleaning are lost. Such interference material will impair coating adhesion and can serve to wick moisture through the coating directly to the steel.

- 4.8.1 Inspect the surfaces prior to coating application to assure that abrasive residues have been removed and that the surface is free from dirt, dust or other debris. Pay specific attention to corners and inaccessible areas for pockets of abrasive that may remain. In addition, be certain that the scaffolding has been thoroughly blown down to remove pockets of dust or abrasive which could be dislodged during the coating operation. The dust cleanliness at this point is even more critical if airless spray is to be employed, since the airless gun cannot be used to blow down the surface prior to application, as is the case with a conventional gun.
- 4.8.2 The prepared surfaces shall be painted within 8 hours after cleaning and prior to the formation of flash rusting. During the cleanliness inspection, pay special attention to assure that flash rusting has not occurred. If present, mark for removal or to be isolated from painting. If isolated from painting, assure that the areas are recleaned and painted at a later time. The recleaning shall involve blast cleaning, as power tools tend to polish the surface providing an unacceptable smoothness for adhesion of the epoxy zinc-rich coating.

5.0 Mixing and Thinning

Mixing - Thorough mixing of the epoxy zinc materials is essential to assure that pigments and zinc have not settled out into the bottom of the container(s) and that a homogenous blend results. Improper mixing of this material will allow for the erratic deposition of the zinc dust throughout the applied film. This results in agglomerations of the zinc which can create voids, pinholes, and localized areas of high moisture permeability, and also can cause "zinc-poor" areas which will provide less galvanic protection of the substrate

Thinning - The thinning requirements for the various materials are provided along with the mixing instructions below. The amount of thinner to be added depends upon the temperatures at the time of application. Generally, more thinner is added at higher temperatures because as the temperatures increase, the speed at which the thinners evaporate also increases. Thus, it can be difficult to apply a continuous wet film due to such rapid evaporation. In such cases, additional thinning is necessary. Conversely, less thinner is used at lower temperatures to decrease the "wet time" and reduce the possibility of runs, sags, and solvent entrapment.

If a good wet coat is not applied, the coating will not flow together properly and the result will be porosity and poor adhesion to the steel and bubbling of the topcoat.

- 5.1 Assure that adequate ventilation has been provided in the mixing area. All mixing buckets and paddles must be clean of old paint and debris. Otherwise, the new paint can become contaminated.
- 5.2 Inspect the material delivered to the mixing site for coating type and condition of cans. Leaky containers or containers showing corrosion on the inside should be rejected and reported to a supervisor as they indicate potential problems.
- 5.3 Material which has exceeded its shelf life should be segregated from use and reported to a supervisor. The shelf life of the epoxy materials is generally 9 months to 1 year. Older material is most likely satisfactory; however, samples must be sent to the USA-CERL laboratory for recertification prior to use.
- 5.4 Record the batch numbers of the material. Observe and record the mixing and thinning procedures and amounts. It is best to have all materials at least 55°F prior to mixing so that proper hemica cross-linking can occur. Thinning up to 15% with methyl ethyl ketone (MEK) or NP-20 is normally required when the ambient temperatures are less than 80°F. NP-20 is the preferred thinner for normal use.

5.5 Mixing Instructions

It is preferred that only complete kits of this material (E-303) be mixed at any time. The standard kit contains 2.85 gallons and consists of three parts: Component A (1.0 gallon), Component B (1.0 gallon), and Component C-Zinc Dust (50.0 pounds). Thoroughly power stir the paint (Component A), add Component B, and blend together. While agitation continues, slowly sift the zinc dust (Component C) into the mixture and continue power agitation until the zinc dust has been thoroughly dispersed. After mixing, inspect the bottom of the containers to ensure that no lumps or settlement remain. The speed of mixing need only be rapid enough to blend the material together, but not so rapid as to entrain air into the paint. Prior to use, strain the mixture through a

30-60 mesh screen to prevent zinc dust slugs from reaching the spray gun nozzle.

Mixes of larger or smaller sizes will be permitted, provided that the quantity relationship of the components is the same as above (e.g., 1/2 gallon-A, 1/2 gallon-B, 25 pounds-C). Note that Type II zinc dust should be specified if the system is to be used in potable water tanks.

It is essential that agitation be continued without interruption during all spraying to keep the zinc powder from settling to the bottom of the spray pot. The speed of agitation need only be enough to keep the zinc in suspension, but not so fast as to entrain air into the mixed paint.

- 5.6 The pot life of the epoxy zinc-rich material thinned from time to time with small amounts of thinner will normally be in excess of 24 hours, but may be less in warm weather. Pot life decreases with increasing temperature; and conversely, it increases as the temperature decreases. Pot life ends when the coating material loses body and begins to sag during application. Note: Pot life commences at the time Components A, B and C are combined.

6.0 Application Equipment

- 6.1 Epoxy zinc-rich paint shall be spray applied, except that areas inaccessible to spraying may be brushed. Conventional spray is preferred over airless because of better control in confined areas. Airless spray, however is approved for use, provided that application results are satisfactory.
- 6.2 Record the type of application equipment used including the manufacturer, identification of tips, needles, nozzles, hose sizes and lengths, and so forth.
- 6.3 The following spray equipment is suitable for the application of the epoxy zinc-rich coatings, although equivalent equipment can be substituted. The application equipment shall be kept clean and in good mechanical condition.

Conventional Spray - Epoxy Zinc-Rich Formulation

Spray gun: industrial quality gun such as Binks 18 or DeVilbiss MBC or JGA.

Fluid tip: large enough orifice to allow passage of solids and zinc powder without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Suitable tips are Binks 66 or DeVilbiss E.

Air cap: sized with sufficient air openings to atomize the paint stream without so many openings to cause excessive solvent evaporation prior to deposition of the paint film. Suitable caps are Binks 66 PE or 63 PB or DeVilbiss 704, 765, or 78.

Air hose: 5/16 in. ID provides the proper volume of air.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too great a restriction, while larger hoses allow too much material to flow and compound the zinc settling problem.

Hose lengths: less than 150 ft is preferred with 50 to 100 ft common. The hoses should be as short as possible. Longer hoses allow the solids to settle in the line prior to reaching the spray gun. This leads to clogging and the application of nonhomogenous films.

Atomization pressure: only enough air pressure to atomize the paint without creating dryspray; usually 50 to 60 psi at the gun.

Spray pot: the spray pot must be equipped with an agitator.

Airless Spray - Epoxy Zinc-Rich Formulation

Airless spray is permitted for use, but note that the use of conventional spray is strongly recommended for the epoxy zinc-rich system. This is because airless spray is difficult to control, especially in confined areas and because of problems with plugged spray tips. Much of this can be avoided by the use of conventional spray because of better controls on the gun and larger fluid orifices. Historically, many more quality problems have resulted from the use of airless spray for these materials.

Spray gun: industrial quality spray gun such as a Binks 500 or Graco 208-663 or 205-591.

Fluid tip: large enough orifice to allow passage of solids and zinc powder without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Note that reversible tips are very helpful because of the speed with which clogs can be removed, and adjustable tips are beneficial for complex structures. This allows for the immediate changing of the spray pattern size (by changing the orifice size) at the spray gun. The smallest orifice diameter provides the best atomization because the volume of paint is being forced through a smaller opening. The orifice size for epoxy zinc-rich paint is generally .017 to .027 in. maximum.

Alternatively, there are "ball tips" available which combine two separate tips of the same orifice with different fan widths on the same ball. These tips provide a narrow fan for small surfaces and a wide fan for larger surfaces. Fan width tip combinations range from 2-4 in./6-8 in. up to 2-4 in. /16-18 in.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too much of a restriction, while larger hoses may allow too much material to flow.

Hose lengths: there are generally no restrictions on the hose length for airless spray. However, less than 150 ft is preferred because a larger hose causes a pressure drop. If, for example, a 20:1 pump is being used and 1800 psi is required for proper atomization, the use of a very long hose length may cause such a pressure drop at the gun that proper atomization is not possible. In such a case, a smaller tip would be necessary (if possible) or a larger pump with a higher compression ratio would be necessary.

Spray pump: the spray pump should be capable of providing from 2000 psi to 3000 psi paint to the spray gun. This pressure is generally adequate for proper atomization of the epoxy zinc-rich material. If tails in the spray pattern form, the pressure needs to be increased. If increasing the pressure does not solve the

problem, then the tip is clogged or worn. Although the higher pressures are necessary to eliminate the tails, ideally the pressures should be kept as low as possible to reduce the velocity of the paint. This reduces splashing and provides a more uniform film.

7.0 Application

- 7.1 Ventilation/Safety - During mixing, local exhaust ventilation shall be provided in the area where curing agent (Part B) and resin (Part A) are mixed. The exhaust ventilation shall be capable of providing 100 feet per minute of air flow at the mixing station. The ventilation can be natural or mechanical. Butyl gloves, apron, and a chemical face shield must be worn. Skin contact with the epoxy resin should be avoided because of the flammability of the solvents, explosion-proof mixers should be used and smoking should be prohibited.

For shop application (if quantities of 10 gallons or more are used), an eye lavage and deluge shower must be provided in the mixing area. If eyes are contaminated, copious quantities of water should be used to irrigate the eyes for about 15 minutes. Medical attention should then be sought. When painting in enclosed spaces, sufficient exhaust ventilation shall be provided to exchange the air with fresh air at a rate of 5000 cubic feet per minute for each spray gun in operation.

- 7.1.1 Make periodic tests to assure that the vapors are not accumulating and that the enclosed spaces are safe from fire and explosion hazards. Use a calibrated explosimeter or organic vapor analyzer.

- 7.1.2 Verify that the spray painters and other personnel in the work area are wearing air-fed hoods or cartridge-type respirators suitable for use with epoxy coatings.

- 7.2 Ambient Conditions - The epoxy zinc-rich formulations can be applied at ambient and surface temperatures between 50°F and 125°F. However, temperatures between 50°F and 100°F are preferred because lower temperatures will prevent the coating from curing, while higher temperatures cause rapid flash-off of the solvents resulting in a "dry" film that does not flow or knit together. In either case, it is difficult to achieve a pinhole-free film that is suitable to withstand immersion service.

- 7.2.1 Monitor the ambient conditions with a sling psychrometer and surface temperature thermometer every four hours or more frequently if extremes are being encountered.

- 7.2.2 Verify that the air temperatures are between 50°F and 100°F (minimum 50°F; maximum 25°F), the surface temperature is at least 5°F greater than the ambient dew point temperature and the relative humidity is less than 90 percent.

- 7.3 Agitation - During application, constant agitation is *mandatory* for E-303.

- 7.3.1 Verify that an agitator is in operation during the use of the epoxy zinc-rich coating.

7.3.2 If spraying is resumed after any interruption of longer than 15 minutes, verify that the entire length of the material hose is whipped vigorously in order to redisperse any settled zinc.

7.3.3 If the painting operation is to be suspended for more than an hour, verify that the paint is emptied from the material hose and maintained under constant agitation.

7.4 Spray Technique/Time Between Coats

7.4.1 The coatings are applied using a single spray coat. Verify that standard good spray techniques are being used:

- a. The spray gun must be held perpendicular to the surface at all times as arcing will create erratic thicknesses and overspray/dryspray.
- b. The gun-to-surface distance should be held constant (6 in. to 10 in. for conventional and 12 in. to 16 in. for airless) to avoid too heavy or dry a coat.
- c. The trigger should be released at the end of each pass to avoid excessive film build.

7.4.2 Verify that each coat of the epoxy zinc-rich material is applied as a single spray coat. This single spray operation (per coat) consists of a preliminary extra pass on edges, corners, angles, seams, crevices, weld lines, and similar surface irregularities. Such irregularities shall be sprayed from every direction in order to assure complete coverage of all surfaces. After the preliminary spray pass, the paint shall be applied in a single pass (50 percent overlap per pass). This represents one single spray coat.

7.4.3 At anytime up to eight days, another spray coat (50 percent overlap per pass) shall be applied at right angles to the first (whenever possible). This "cross-hatch" technique helps to even-up coating thicknesses and to ensure that there are no skips or misses. The minimum time between coats need only be such that recoating does not cause running or sagging. The eight-day maximum time to recoat is permitted provided that the first coat is void-free and thick enough to prevent rusting.

Pits, cracks, and crevices shall be filled with paint insofar as practicable (without detrimental pinholes), but in any event all pit surfaces shall be thoroughly covered and all cracks and crevices sealed off against the entrance of moisture.

7.4.4 Subsequent coats of paint (epoxy or coal tar epoxy) must be applied after a drying/curing period of not less than six hours nor more than 96 hours. If the second coat of epoxy zinc-rich paint has been shop applied or otherwise has cured for longer than 96 hours, it shall be completely recoated with an additional thin "tack coat" of the epoxy zinc-rich paint. This "tack coat" should then be overcoated within 96 hours with the appropriate topcoat(s).

8.0 Thickness and Coverage

The epoxy zinc-rich paint (E-303) is used as a primer beneath epoxy (MIL-P 24441) or coal tar epoxies (200 or C-200a). The application of these materials is not covered by this procedure. The epoxy zinc-rich should be applied so as to cover approximately 350 square feet per gallon to yield an average dry film thickness of not less than 3.0 mils and a thickness not less than 2.5 mils *at any point*.

9.0 Inspection of Each Coat

It is important to examine each coat prior to application of the next for film thickness and cleanliness. Insufficient film thicknesses per coat can lead to pinpoint rusting prior to application of the next due to the presence of exposed peaks of the surface profile. This is particularly critical for the first or second coats if subsequent coats are not to be applied until a day or more later. Excessive film builds per coat can result in solvent entrapment and the formation of pinholes, both of which increase the moisture permeability of the paint system. Dirt or debris trapped within or between coats can lead to poor adhesion and blistering in service. Debris projecting through the film can serve to wick water through the coating directly to or close to the substrate.

- 9.1 Make certain that all coats are being applied in the proper sequence and color. The epoxy zinc-rich material is green.
- 9.2 Do not inspect the surface until the coating has dried and cured to the degree that it can support handling without damage.
- 9.3 Inspect for surface dirt or debris prior to the application of subsequent coats. If present, it must be removed.
- 9.4 Report the presence of pinpoint rusting to a supervisor for resolution. Minor localized areas may be repaired by hand-sanding followed by application of the material. Larger areas may require complete blast cleaning.
- 9.5 Inspect the coating thickness using a nondestructive magnetic dry film thickness gage.
 - 9.5.1 Perform only a cursory thickness inspection between coats in order to minimize the time spent on the coating and to avoid unnecessary contamination. Note that if the epoxy zinc-rich is soft or tacky, a reasonably accurate measurement will not be possible. As the instrument probe will deform the coating or "stick" during pull-off type measurements (e.g., Mikrotest). Therefore, if it is necessary to measure the thickness while the paint is still slightly soft (in order to permit the next coat to be applied), a plastic shim of known thickness can be placed between the instrument magnet and the paint. By subtracting the thickness of the shim from the total measurement, a reasonably accurate assessment of the coating thickness can be made. Guidelines for the thickness of each coat were provided above. These guides are not absolute requirements in all cases, but they help to ensure that the total system thickness and continuity requirements will be achieved.
 - 9.5.2 For the inspection of the complete system, take a minimum of 15 readings per 100 square feet of large, flat surfaces (e.g., dam gate). The

15 readings should be made in five clusters of three readings each. Each cluster should cover a few square inches.

The number of readings on complex surfaces shall be significantly greater than those above for large, flat surfaces. All locations of all complex surfaces must be measured as these are the areas that historically fail first due to insufficient or excessive paint coverage. The specific number of readings is dependent upon the results obtained. Initially, a minimum of three readings for every 4 to 5 square feet should be made. If the readings continue to be satisfactory, the frequency can be reduced. If unsatisfactory, the frequency shall be increased.

The average of all of the readings must be at least 3.0 mils. Single clusters can measure as low as 2.5 mils. Any readings less than 2.5 mil are unacceptable.

9.5.3 Report the presence of insufficient or excessive film thickness to a supervisor. Insufficient thickness can generally be corrected by the application of an additional coat to the deficient areas. The resolution of excessive film thickness is dependent upon the continuity and condition of the film.

9.6 Visually inspect each coat and the final system for runs, sags, holidays, pinholes, and overspray/dryspray. Note that the purpose of the epoxy zinc-rich paint is for protection, and therefore a void-free film is necessary. Runs or sags which do not contain pinholes or voids normally need not be removed.

9.6.1 A holiday detector may be useful in assisting in the final system inspection for the presence of holidays, excessively thin areas (e.g. on edges), voids, and pinholes. Of course, the wet sponge holiday detector would not be used directly on the epoxy zinc-rich primer, but rather after application of the entire system is complete.

9.6.2 The use of the holiday detector is described in the instrument section of the procedures, but basically it involves a wetted sponge electrode which is grounded to the surface through the detection unit. The sponge is passed across the surface and the water penetrates pinholes or flaws in the coating system to complete a circuit. A bell or buzzer rings each time a flaw is encountered.

9.7 Mark all defective areas for repair using chalk or a marker designated by a supervisor. Reinspect the reworked areas in accordance with this procedure to assure final specification compliance.

10.0 Record Keeping

It is crucial to be certain that all painting records (see Daily Inspection Checklist in Appendix A) are properly recorded and filed for each project. The painting record is the only written verification of what was actually done at the time. If questions arise later, the records will be the only source of information or clues as to the material, equipment, and atmospheric conditions at the time of surface preparation, coating application, and cure.

Oil Base Systems

1.0 Systems and Use

- 1.1 This inspection procedure is applicable to the following oil base materials and Corps of Engineers systems:

Oil Base Coatings:

TF-P-86 Type I & II (Federal specification covering red lead/linseed oil Type I and red lead/alkyd linseed oil based paints type II).

TF-P-38 (Federal specification for an aluminum flake based pigment in a phenolic resin varnish).

TT-P-615 Types I & II (Federal specification covering lead silico chromate pigment in a linseed oil vehicle).

TT-P-489 Class A (Federal specification for an alkyd gloss enamel).

Corps Systems: 1, 2, 8, 9, 16.

- 1.2 Specific properties and compatibility problems with some of the oil based materials are as follows:

TT-P-86 - Types I & II Red Lead/Oil Coatings

Type I - Red lead, linseed oil

Type II - Red lead, mixed pigment, alkyd varnish, linseed oil

- a. Self-priming
- b. Require only power tool or brush-off blast cleaning.
- c. Cannot be used as primer for coatings containing strong solvents (e.g., vinyls) as lifting may occur.
- d. Both Types I & II have good corrosion inhibiting capabilities.
- e. Type II is faster drying than Type I.

TT-P-38 - Aluminum Ready Mixed

Flake aluminum in a phenolic resin varnish of 33 gallon oil length.

- a. Self-priming or may be used as a topcoat over other primers.
- b. May be used on wood or metal.
- c. Excellent durability when exposed to moist or salty atmospheric conditions or occasional immersion.

TT-P-615 - 93 Percent Basic Lead Silico Chromate/Oil Coatings

Pigment is as follows:

93 percent Basic Lead Silico Chromate

73 percent Iron Oxide

- a. Self-priming**
- b. Improved weathering resistance versus TT-P-86 above.**
- c. Type II versus Type I is faster drying but gives a less flexible film.**

2.0 General Requirements for Inspections

- 2.1 Wear proper protective clothing including clean gloves to preclude contamination of the surfaces to be inspected.**
- 2.2 Assure that proper lighting and adequate accessibility to areas to be inspected have been provided.**
- 2.3 Conduct inspections in a planned and controlled manner in accordance with this inspection plan. Divide large areas into smaller segments to organize structures for proper inspection coverage.**
- 2.4 Document the results of all inspections on the Daily Painting Inspection Report Form.**
- 2.5 Use inspection instrumentation in accordance with the Use and Calibration of Inspection Instrumentation procedure in Appendix C.**

3.0 Continuous Inspections

The following inspections are performed during all phases of the blast cleaning and painting work, and as such, are termed continuous inspections.

3.1 Protective Coverings

Blast cleaning dust, abrasives, and paint overspray can damage or impair the operation of certain equipment and structures in the work area. Therefore, protective coverings must be properly installed and remain intact.

- 3.1.1 Prior to blast cleaning/coating application in a given area, inspect to assure that galvanized, stainless steel surfaces, bearings, gages, previously completed coating work, and any other items designated by the supervisor, have been suitably masked and protected from the coating operations.**
- 3.1.2 Spot-check all masking during work to assure that it remains intact. If the masking is loosened or removed, notify the contractor so that repairs can be made immediately.**

3.2 Ambient Conditions

If moisture condenses on a prepared steel surface, corrosion will result prior to the application of the protective coating. Also, moisture condensation on a coating prior to sufficient solvent release can affect its curing. Insufficient or excessive air and surface temperatures during application can lead to the entrapment of solvents or the formation of a dry paint film that does not knit and flow together properly. Therefore, it is important to monitor the ambient conditions during all work.

- 3.2.1 Monitor the ambient conditions and surface temperatures approximately every 4 hours during surface preparation and coating application (or more frequently if extremes are being approached). Use a psychrometer and surface temperature thermometer in the general location of the areas being worked.
- 3.2.2 The surface temperature should be at least 5°F higher than the dew point temperature during final surface preparation or coating application to eliminate the possibility of moisture condensation.
- 3.2.3 The relative humidity should be less than 90 percent during surface preparation or coating application in order to eliminate condensation problems.
- 3.2.4 There are no limits on the surface and ambient temperatures for surface preparation. However, for application, the temperatures must be between 45°F to 125°F, and preferably between 50°F to 100°F.
- 3.2.5 Work should not be performed in the fog, rain, or snow.

3.3 Compressed Air Cleanliness

The cleanliness of the compressed air is important to assure that moisture or oil is not deposited onto the surface during blast cleaning, blow down, or when using conventional air spray. Moisture in the air supply can cause blistering of the coatings. Oil contamination will not allow the coating to adhere to the steel and will also create craters or fisheyes in the applied film.

- 3.3.1 Test the compressed air to be used for blast cleaning, blow down, and conventional spray application to assure that it is free from moisture and oil. At a minimum, test the air supply every 4 hours for every compressor system in operation.
- 3.3.2 Determine air cleanliness downstream of moisture and oil separators. Hold a clean white piece of blotter paper approximately 18 in. from the air supply for 1 to 2 minutes. If, at the end of that time, no moisture or discoloration is visible on the blotter paper, the air is acceptable.
- 3.3.3 If the air is unacceptable, all quality-related work using the compressed air system found to be contaminated should be halted. Inspect the work completed between the last "good" test and the unacceptable one for signs of damage due to moisture or oil contamination. When the lines are cleaned, repeat the test before work resumes.

4.0 Surface Preparation

4.1 Equipment and Surroundings

Assure that the "Continuous Inspection" items of Section 3.0 are satisfactory (protective coverings, air cleanliness, ambient conditions) and examine the blast equipment for safety. The blast nozzles must be equipped with operating "dead man" controls which will shut off the abrasive flow if the nozzle is dropped. The hose sections must be connected using external couplings that are locked together with wires. The blasters must be supplied with air-fed hoods that comply with MESA and air purity requirements. Other personnel in the blasting area must use dust masks.

4.2 Sharp Edges and Weld Spatter

Sharp edges and weld spatter are less detrimental to the performance of oil based coatings than to others, due to the service environments involved. Inspect for the presence of sharp edges or weld spatter if directed by a supervisor.

4.3 Grease and Oil

Deposits of grease or oil on the surface must be removed prior to preparation so that they are not impacted into the surface or spread onto areas which have already been prepared. Grease or oil will interfere with the adhesion of the coating.

4.3.1 Prior to blast cleaning, inspect for any deposits of grease or oil. Such deposits shall be Solvent Cleaned in accordance with SSPC-SP1. Solvent cleaning requires the frequent use of new clean cloths and clean solvent to assure that the contaminant is removed, rather than simply spread across the surface.

4.3.2 After cleaning, visually reinspect the areas to ensure that the grease and oil have been removed.

4.4 Nozzle Pressure

Adequate blast pressure at the nozzle is important for productivity. The optimum blasting pressure at the nozzle is 90 to 100 psig. If the pressure drops to 60 psig, the productivity is decreased by 50 percent. Excessive pressures can also be detrimental as the abrasive may be fractured prior to reaching the surface, eliminating its effectiveness. In addition, excessive pressures can lead to greater operator fatigue. Note that the blasting pressure has a greater impact on productivity rather than quality as the same degrees of surface cleanliness and roughness (profile) can be achieved with lesser pressures.

4.4.1 During the initial start-up of the job, record the pressure of the air used for blast cleaning. Take the pressure as close to the blast nozzle as possible using a hypodermic needle pressure gage. Insert the needle through the hose in the direction of the nozzle and record the reading with abrasive flowing. When taking a reading, all nozzles as well as other pneumatic equipment associated with the compressor system should be operating.

- 4.4.2 This reading need only be taken at the beginning of a project or when changes are made in the compressed air system.

4.5 Abrasive Cleanliness/Profile

Clean, dry abrasive is essential for achieving quality work. An oily abrasive will contaminate the surface and a damp abrasive will clog blast pots in addition to creating flash rusting.

The surface roughness or profile of the steel after blast cleaning is also important in that it assures proper adhesion of the coating system, although oil based coatings are more tolerant of "smooth" surfaces than are other materials. For this reason, a specific profile range is not required. However, note that an excessively heavy or deep profile can result in pinpoint rusting caused by peaks of the steel extending through the coating system. Note also soft abrasives may "powder" upon impact, and as such become a weak contaminant that can affect coating adhesion.

- 4.5.1 Visually check the abrasive for dryness and contaminants. If the abrasive is damp or contains numerous particles other than the abrasive material itself, it should not be used.
- 4.5.2 If abrasive is recycled, make certain that it is a steel abrasive or other type which is capable of recycling. Sand shall not be reused. Inspect a sample of the abrasive for oil and grease contamination a minimum of twice daily. Drop a handful of the recycled abrasive into a vial of water (approximately 1 pint) and shake vigorously. The abrasive should not be used if oil is visible on the surface of the water.

4.6 Surface Cleanliness

The surface preparation for each of the above systems requires only power tool cleaning or brush-off blast cleaning.

- 4.6.1 Brush-Off Blast Cleaning - This grade of cleaning is generally used for ferrous surfaces that are subjected to exterior or interior atmospheric exposure. A brush-off blast cleaned surface finish is defined as one from which all oil, grease, dirt, rust scale, loose mill scale, loose rust and loose paint or coatings are removed completely, but tight mill scale and tightly-adhered rust, paint and coatings are permitted to remain provided that all mill scale and rust have been exposed to abrasive blast pattern sufficiently to expose numerous flecks or the underlying metal fairly uniformly distributed over the entire surface. Remaining material is considered to be tight if it cannot be lifted when probing the edges with a dull putty knife.

When a brush-off blast is employed, the welds and adjacent surfaces shall be cleaned thoroughly to an SSPC-SP6 "Commercial Blast" cleanliness.

- 4.6.2 Power Tool Cleaning - Power tool cleaning shall conform with SSPC-SP3 which requires the removal of loose mill scale, loose rust, and loose paint with power wire brushes, power impact tools, power grinders, power sanders, or by a combination of these methods. It is not intended that all mill scale, rust, and paint be removed by this process; but loose mill

scale, loose rust, loose paint, and other detrimental foreign matter shall be removed. Residues are considered to be tight if they cannot be removed by probing the edge with a dull putty knife.

When preparation of the overall surface is carried out by the power tool method, blast cleaning need not be employed to prepare the welds. However, the welds and adjacent areas shall be cleaned thoroughly of flux, rust, and other interference material. After preparation of the welds, brush scrubbing and rinsing with clean water is also required to essentially remove all soluble deposits. Wetting the surfaces during water-washing operations shall be limited to the weld area required to be treated, and such areas shall be recleaned (by power tools) prior to painting to assure that flash rusting is not present. This washing step can be eliminated only if the original power tool cleaning is carried out with such thoroughness as to assure that all deposits (soluble or otherwise) have been removed (e.g., "Bright Metal").

- 4.6.3 During the cleanliness inspection, reexamine the surface for the presence of laminations or other surface imperfections uncovered by abrasive blasting. Report them immediately to a supervisor for resolution.
- 4.6.4 Mark areas for rework that are not in conformance with the specification requirements. Use only those marking devices agreed upon or permitted by the specification or supervisors (e.g., chalk).
- 4.6.5 Reinspect the deficient areas after rework for specification compliance. Continue to mark and reinspect deficient areas until the surface is within specification requirements. Record the final condition of the surface.

4.7 Cleanliness Prior to Coating

The cleaned steel must be free from dust and loose surface deposits prior to coating application, otherwise the benefits of surface preparation are lost. Such interference material will impair coating adhesion and can serve to wick moisture through the coating directly to the steel.

- 4.7.1 Inspect the surfaces prior to coating application to assure that abrasive residues have been removed and that the surface is free from dirt, dust or other debris. Pay specific attention to corners and inaccessible areas for pockets of abrasive that may remain. In addition, be certain that the scaffolding has been thoroughly blown down so that pockets of dust or abrasive are not present which could be dislodged during the coating operation. The dust cleanliness at this point is even more critical if airless spray is to be employed, since the airless gun cannot be used to blow down the surface prior to application, as is the case with a conventional gun.
- 4.7.2 The prepared surfaces shall be painted as soon after cleaning as practical, but in any event prior to the deterioration of the surface. If

deteriorated, mark the area for rework or to be isolated from painting. If isolated from painting, assure that it is recleaned and painted at a later time.

5.0 Mixing and Thinning

Mixing - The coatings covered by this procedure are all single component materials. As a result, it is common to extract portions of the material and reseal the container for later use. If a skin has formed in the container during storage, it shall be removed and discarded prior to mixing.

Mixing shall be done by hand or mechanical means so that lumps are broken and pigments completely dispersed until a homogenous mixture results. The material shall not be used until all settlement in the bottom of the container has been uniformly dispersed through the coating. This is particularly important with paints containing heavy pigments such as TT-P-86 and TT-P-615.

Inspect the material delivered to the mixing site for coating type and condition of cans. Leaky containers or containers showing corrosion on the inside should be rejected and reported to a supervisor as they indicate potential problems.

Thinning - Thinning of no more than 1 pint per gallon of mineral spirits, Federal Specification TT-T-291, is permitted only as necessary to facilitate application.

If natural ventilation is inadequate to prevent fire and explosion hazards in the mixing area, local exhaust ventilation shall be provided. Such ventilation shall be capable of providing 100 feet per minute of air flow at the mixing area.

6.0 Pot Life and Shelf Life

The pot life of single component materials is equivalent to the shelf life provided the containers are tightly sealed after use to prevent evaporation of the volatile material.

The shelf life of these materials is nominally one year. Paint and thinner that is more than one year old is likely to still be good, but should be submitted to USA-CERL for recertification testing.

7.0 Application Equipment

These materials can be applied by brush, roller, or conventional or airless spray.

The following spray equipment is suitable for the application of the oil based coatings, although equivalent equipment can be substituted. The application equipment shall be kept clean and maintained in good mechanical condition.

Conventional Spray

Spray gun: industrial quality gun such as Binks 18 or DeVilbiss MBC or JGA.

Fluid tip: large enough orifice to allow passage of solids without clogging, but not so large as to prohibit atomization of the paint stream into fine

droplets. Suitable tips are Binks 63C or DeVilbiss FF (approximately 0.052 in. ID).

Air cap: sized with sufficient air openings to atomize the paint stream. Suitable caps are Binks 63 PB or DeVilbiss 704.

Air hose: 5/16 in. ID provides the proper volume of air.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too great a restriction, while larger hoses allow too much material to flow.

Hose lengths: less than 150 ft is preferred with 50 ft to 100 ft common. The hoses should be as short as possible.

Atomization pressure: only enough air pressure to atomize the paint without creating dryspray; usually 50-60 psi at the gun.

Airless Spray

Airless spray is permitted for use.

Spray gun: industrial quality spray gun such as a Binks 700 or Graco 205-591.

Fluid tip: large enough orifice to allow passage of solids without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Note that reversible tips are very helpful because of the speed with which clogs can be removed, and adjustable tips are beneficial for complex structures. This allows for the immediate changing of the spray pattern size (by changing the orifice size) at the spray gun. The smallest orifice diameter provides the best atomization because the volume of paint is being forced through a smaller opening. The orifice size for oil based paints is generally in the 0.013 to 0.017 in. range.

Alternatively "ball tips" are available which combine two separate tips of the same orifice with different fan widths on the same ball. These tips provide a narrow fan for small surfaces and a wide fan for larger surfaces. Fan width tip combinations range from 2 - 4 in./6 - 8 in. up to 2 - 4 in./16 - 18 in.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too much of a restriction, while larger hoses may allow too much material to flow.

Hose lengths: there are generally no restrictions on the hose length for airless spray. However, less than 150 ft is preferred because a longer hose causes a pressure drop. If, for example, a 20:1 pump is being used and 1800 psi is required for proper atomization, the use of a very long hose length may cause such a pressure drop at the gun that proper atomization is not possible. In such a case, a smaller tip would be necessary (if possible) or a larger pump with a higher compression ratio would be necessary.

Spray pump: the spray pump should be capable of providing from 2000 psi to 3000 psi paint to the spray gun. This pressure is generally adequate for proper atomization of the oil based materials. If tails in the spray pattern form, the

pressure needs to be increased. If increasing the pressure does not solve the problem, then the tip is clogged or worn. Although the higher pressures are necessary to eliminate the tails, ideally the pressures should be kept as low as possible to reduce the velocity of the paint. This reduces splashing and provides a more uniform film.

8.0 Application

8.1 Ventilation/Safety - When painting in enclosed spaces, sufficient exhaust ventilation shall be provided to exchange the air with fresh air at a rate of 5000 CFM for each spray gun in operation.

8.1.1 Make periodic tests to assure that the vapors are not accumulating and that the enclosed spaces are safe from fire and explosion hazards. Use a calibrated explosimeter or organic vapor analyzer.

8.1.2 Verify that the spray applicators and other personnel in the work area are wearing air-fed hoods or cartridge-type respirators suitable for use with coatings thinned with mineral spirits.

8.2 Ambient Conditions - The oil/alkyd coatings can be applied at ambient and surface temperatures as low as 45°F, but temperatures above 50°F are preferred.

8.2.1 Monitor the ambient conditions with a sling psychrometer and surface temperature thermometer every 4 hours or more frequently if extremes are being encountered.

8.2.2 Verify that the air temperatures are between 50° and 100°F (minimum 45°F; maximum 25°F), the surface temperature is at least 5°F greater than the ambient dew point temperature, and the relative humidity is less than 90 percent.

8.3 Spray Technique

8.3.1 The coatings are applied using a single spray coat. Verify that standard good spray techniques are being used:

- a. The spray gun must be held perpendicular to the surface at all times as arcing will create erratic thicknesses and overspray/dryspray.
- b. The gun-to-surface distance should be held constant (6 to 10 in. for conventional and 12 to 16 in. for airless) to avoid too heavy or dry a coat.
- c. The trigger should be released at the end of each pass to avoid excessive film build.
- d. Regardless of the formulation applied, pits, cracks, and crevices shall be filled with paint insofar as practicable, but in any event all pit surfaces shall be thoroughly covered and all cracks and crevices sealed off against the entrance of moisture.

- 8.3.2 Spray application should be performed using 50 percent overlap of each spray pass. To provide uniformity in thickness and complete coverage, the second set of spray or brush passes (or coats) shall be applied at right angles to the first whenever possible.

Edges, corners, angles, seams, crevices, weld lines, and similar surface irregularities shall receive a preliminary extra spray pass, or brush application for each coat. Such irregularities shall be coated from every direction in order to assure complete coverage of all surfaces.

9.0 Thickness and Coverage

Table B1 identifies the coating materials to be used for each Corps of Engineers painting system, the coverage rate per coat, and the number of coats to be applied.

10.0 Inspection of Each Coat

It is important to examine each coat prior to application of the next for coverage, cleanliness, solvent entrapment, wrinkling, runs, sags, waves, ridges, etc. Dirt or debris trapped within or between coats can lead to poor adhesion. Debris projecting through the film can serve to wick water through the coating directly to or close to the substrate.

- 10.1 Make certain that all coats are being applied in the proper sequence and color. Table A1 provides this information for all systems.
- 10.2 Do not inspect the surface until the coating has sufficiently dried and cured to the degree that it can support handling without damage.
- 10.3 Inspect for surface dirt or debris prior to the application of subsequent coats. If present, it must be removed.
- 10.4 Minor localized areas containing rusting or other defects (i.e., runs, wrinkles) may be repaired by hand sanding followed by application of the material. Large areas may require other repair procedures.
- 10.5 The actual thickness of these oil based systems is not defined per se by the Corps. The actual surface area covered per gallon of paint must not exceed the spreading rates prescribed. In any event, the combined coats for each system must completely hide the base surface and each successive coat must completely hide undercoats of dissimilar color.

Report the presence of insufficient or excessive film thickness to a supervisor. Insufficient thickness can generally be corrected by applying an additional coat to the deficient areas. The resolution of excessive film thickness depends on whether any flaws are present in the film.

- 10.6 Visually inspect each coat and the final system for runs, sags, holidays, pinholes, and overspray/dryspray.
- 10.7 Mark all defective areas for repair using chalk or a marker designated by a supervisor. Reinspect the reworked areas in accordance with this procedure to assure final specification compliance.

11.0 Curing Between Coats

There are no limitations regarding the minimum drying time between coats, provided that recoating does not cause running, sagging, or bleed through.

Likewise, there are no restrictions on the maximum dry time between coats provided the surface is clean from grease, oil, and other debris. If the surface has weathered for a lengthy period (e.g., 6 months or longer) special roughening may be required as directed by a supervisor. The paint shall be considered dry for recoating when it feels firm, does not deform or feel sticky under moderate pressure of the finger.

12.0 Record Keeping

It is crucial to be certain that all painting records (see Daily Inspection Checklist in Appendix A) are properly recorded and filed for each project. The painting record is the only written verification of what was actually done at the time. If questions arise later, the records will be the only source of information or clues as to the material, equipment, and atmospheric conditions at the time of surface preparation, coating application, and cure.

Table B1

Oil Base Systems and Number of Coats

System	Method of Surface Prep.	Mat'l	Coverage Per Coat (sq ft/gal)	Number of Spray Coats
1	Power Tool	TT-P-86	600	1 or 2*
		Type I		
		TT-P-38	450	2
		Total		3 or 4
	Blast Clean	TT-P-86	450	1 or 2*
		Type II		
		TT-P-38	450	2
		Total		3 or 4
2	Power Tool	TT-P-615	600	1 or 2*
		Type I		
		TT-P-38	450	2
		Total		3 or 4
	Blast Clean	TT-P-615	450	1 or 2*
		Type II		
		TT-P-38	450	2
		Total		3 or 4

TABLE B1 (Cont'd)

System	Method of Surface Prep.	Mat'l	Coverage Per Coat (sq ft/gal)	Number of Spray Coats
8	Power Tool	TT-P-86	600	2
		Type I		
		TT-P-38**	450	1
		Total		2 or 3
	Blast Clean	TT-P-86	450	2
		Type II		
		TT-P-38**	450	1
		Total		2 or 3
9	Power Tool	TT-P-615	600	2
		Type I		
		TT-P-38**	450	1
		Total		2 or 3
	Blast Clean	TT-P-615	450	2
		Type II		
		TT-P-38**	450	1
		Total		2 or 3
16***	Power Tool	TT-P-86	450	1
		Type II		
	or Blast Clean	TT-E-489		2
		Total		3

Note: if primer was shop applied, bare metal and damaged areas shall be cleaned and spot primed by brush.

*If specified in severe environments, a second prime coat may be used to create a four-coat system.

**Third coat used in areas of exposure characterized by prolonged or frequent high humidity or condensation.

***This system shall not be applied to machine finished surfaces. Pipe threading and cutting lubricants shall be removed by solvent washing prior to application of paint to piping surface.

Vinyl Butyral Wash Primer (DOD-P-15328)

1.0 Systems and Use

- 1.1 This inspection procedure is applicable to the vinyl butyral wash primer material and certain Corps of Engineers systems:

Wash Primer Coatings: Vinyl butyral wash primer DOD-P-15328

Corps Systems: 13, 14, 15

Note: System 13 uses the wash primer with TT-P-38 (aluminum) as a topcoat. System 14 uses the wash primer with TT-E-489 (Class A) as a topcoat. System 15 uses the wash primer and the topcoat consists of whatever coating is applied to adjacent areas. Application of these oil based paints is not covered by this procedure.

- 1.2 Specific properties and compatibility problems with the use of the wash primer materials are as follows:

DOD-P-15328

- a. Self-priming.
- b. Requires high degree of surface cleanliness as it will not adhere to rust, grease, dirt, oil, etc.
- c. This material is used only as a pretreatment over galvanized, aluminum, aluminum alloy, copper, or steel surfaces. It is not a complete system in itself.
- d. Topcoat can be aluminum paint (TT-P-38), alkyd enamel (TT-E-489), interior latex (TT-P-29) or interior alkyd (TT-P-30). The application of these materials is not covered by this procedure.

2.0 General Requirements for Inspections

- 2.1 Wear proper protective clothing including clean gloves to preclude contamination of the surfaces to be inspected.
- 2.2 Assure that proper lighting and adequate accessibility to areas to be inspected have been provided.
- 2.3 Conduct inspections in a planned and controlled manner in accordance with this inspection plan. Divide large areas into smaller segments to organize structures for proper inspection coverage.
- 2.4 Document the results of all inspections on the Daily Painting Inspection Report Form.
- 2.5 Use inspection instrumentation in accordance with the Use and Calibration of Inspection Instrumentation procedure in Appendix C.

3.0 Continuous Inspections

The following inspections are performed during all phases of the blast cleaning and painting work, and as such, are termed continuous inspections.

3.1 Protective Coverings

Solvents and paint overspray can damage or impair the operation of certain equipment and structures in the work area. Therefore, protective coverings must be properly installed and remain intact.

- 3.1.1 Prior to blast cleaning/coating application in a given area, inspect to assure that stainless steel surfaces, bearings, gages, previously completed coating work, and any other items designated by the supervisor, have been suitably masked and protected from the coating operations
- 3.1.2 Spot-check all masking during work to assure that it remains intact. If the masking is loosened or removed, notify the contractor so that repairs can be made immediately.

3.2 Ambient Conditions

Ideally, the coating should be applied over clean, dry steel. If some slight moisture has condensed on a prepared steel surface immediately prior to the application of the wash primer coating, it may be painted over provided that adequate normal butanol is used as the thinner (see Paragraph 5.4). If the surface is excessively wet, the vinyl butyral resin will be thrown out of solution acid to form a gel. Alternatively the dried film may turn white, become brittle, and lack adhesion to the steel.

Also, moisture condensation on the wash primer prior to sufficient solvent release can affect its curing. Insufficient or excessive air and surface temperatures during application can lead to the entrapment of solvents or the formation of a dry paint film that does not knit and flow together properly. Therefore, it is important to monitor the ambient conditions during all work.

- 3.2.1 Monitor the ambient conditions and surface temperatures approximately every 4 hours during coating application (or more frequently if extremes are being approached). Use a psychrometer and surface temperature thermometer in the general location of the areas being worked.
- 3.2.2 The surface temperature should be at least 5°F higher than the dew point temperature during coating application to eliminate the possibility of moisture condensation.
- 3.2.3 The relative humidity should be less than 90 percent to eliminate condensation problems.
- 3.2.4 There are no limits on the surface and ambient temperatures for surface preparation. However, for application, the temperatures must be between 35°F to 125°F, and preferably between 50°F to 100°F.
- 3.2.5 Work should not be performed in the fog, rain, or snow.

3.3 Compressed Air Cleanliness

The cleanliness of the compressed air is important to assure that moisture or oil is not deposited onto the surface during blow down, or when using conventional air spray. Moisture in the air supply can cause adhesion loss or blistering of the coatings. Oil contamination will not allow the vinyl butyral wash primer coating to adhere to the clean metal and will also create discontinuities in the applied film.

3.3.1 Test the compressed air to be used for blow down and conventional spray application to assure that it is free from moisture and oil. At a minimum, test the air supply every 4 hours for every compressor system in operation.

3.3.2 Determine air cleanliness downstream of moisture and oil separators. Hold a clean white piece of blotter paper approximately 18 in. from the air supply for 1 to 2 minutes. If, at the end of that time, no moisture or discoloration is visible on the blotter paper, the air is acceptable.

3.3.3 If the air is unacceptable, all quality-related work using the compressed air system found to be contaminated should be halted. Inspect the work completed between the last "good" test and the unacceptable one for signs of damage due to moisture or oil contamination. When the lines are cleaned, repeat the test before work resumes.

4.0 Surface Preparation

4.1 Sharp Edges and Weld Spatter

Sharp edges and weld spatter can be detrimental to coating performance as the coating will draw thin on these areas to provide insufficient protection. In addition, weld spatter can become dislodged in service removing the coating with it.

4.1.1 Inspect for the removal of sharp edges, weld spatter, and laminations to the extent directed by the supervisor.

4.2 Surface Cleanliness

A high degree of surface cleanliness is necessary for the proper adhesion and performance of butyral wash primer systems. Debris, old paint, grease, or oil will interfere with the adhesion and performance of the systems. Grease and oil shall be solvent cleaned with mineral spirits in accordance with SSPC-SP1. Solvent cleaning requires the frequent use of new clean cloths and clean solvent to assure that the contaminant is removed, rather than simply spread across the surface.

Touching the steel with bare hands can also affect performance as the oils and salts from the skin can cause adhesion loss if painted over. Greasy, oily gloves must also not be allowed to contact the cleaned surface.

4.2.1 Inspect 100 percent of the cleaned surface for compliance with the above and pay particular attention to rivet heads, backside of angles, and

inaccessible areas as these are historically the most poorly prepared. If necessary, use a mirror to view these areas.

- 4.2.2 Inspect with the unaided eye. However, a five-power hand magnifier may be used as required to verify surface cleanliness.
- 4.2.3 During the inspection, re-examine the surface for the presence of sharp edges, weld spatter, or surface irregularities previously missed. Report them immediately to a supervisor for resolution.
- 4.2.4 Mark areas for rework that are not in conformance with the specification requirements. Use only those marking devices agreed upon or permitted by the specification or supervisors (e.g., chalk). Do not use wax crayons as the vinyl butyral wash primer will not adhere if it is not completely removed during the rework.
- 4.2.5 Re-inspect the deficient areas after rework for specification compliance. Continue to mark and re-inspect deficient areas until the surface is within specification requirements. Record the final condition of the surface.

5.0 Mixing, Thinning, and Pot Life

Thorough mixing of the vinyl butyral wash primer material is essential to assure that pigments have not settled out into the bottom of the containers and that a homogenous blend results.

- 5.1 Assure that adequate ventilation has been provided in the mixing area. All mixing buckets and paddles must be clean of old paint and debris. Otherwise, the new paint can become contaminated.
- 5.2 Inspect the material delivered to the mixing site for coating type and condition of cans. Leaky containers should be rejected and reported to a supervisor.
- 5.3 Material which has exceeded its shelf life should be segregated from use and reported to a supervisor. The shelf life of the vinyl butyral wash primer materials is generally 9 months to 1 year. Older material is most likely satisfactory; however, samples must be sent to the USA-CERL laboratory for recertification prior to use.
- 5.4 Record the batch numbers of the material. Observe and record the mixing and thinning procedures and amounts. It is best to have all materials at room temperature prior to thinning in order to better control the viscosity.

The pretreatment primer (DOD-P-15328) shall be mixed by slowly adding one volume of acid component (diluent) to four volumes of resin component (base solution) with constant stirring. If wet spray is not maintained, small quantities of normal Butanol (ASTM D304) can be added. The acid component (diluent) over and above the amount specified above must not be used for thinning purposes.

- 5.5 After mixing, inspect the bottom of the containers to ensure that no lumps or settlement remain.

5.6 The pot life of the vinyl-butyral wash primer material after mixing is six to eight hours. Discard material after eight hours.

6.0 Application Equipment

- 6.1 Vinyl butyral wash primer paint shall be spray applied, except that areas inaccessible to spraying may be brushed.
- 6.2 Record the type of application equipment used including the manufacturer, identification of tips, needles, nozzles, hose sizes and lengths, and so forth.
- 6.3 The following spray equipment is suitable for the application of the vinyl butyral wash primer, although equivalent equipment can be substituted. The application equipment shall be kept clean and maintained in good mechanical condition.

Conventional Spray - Vinyl Butyral Primer

Spray gun: industrial quality gun such as Binks 18 or DeVilbiss MBC or JGA.

Fluid tip: large enough orifice to allow passage of the material without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Suitable tips are Binks 63 or DeVilbiss FF.

Air cap: sized with sufficient air openings to atomize the paint stream without so many openings to cause excessive solvent evaporation prior to deposition of the paint film. Suitable caps are Binks 63 PB or DeVilbiss 704.

Air hose: 5/16 in. ID provides the proper volume of air.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too great a restriction, while larger hoses allow too much material to flow.

Hose lengths: less than 150 ft is preferred with 50 to 100 ft common. The hoses should be as short as possible. Longer hoses allow the solids to settle in the line prior to reaching the spray gun. This leads to the application of nonhomogenous films.

Atomization pressure: only enough air pressure to atomize the paint without creating dryspray; usually 50 to 60 psi at the gun.

Airless Spray - Vinyl Butyral Wash Primer

Airless spray is permitted for use.

Spray gun: industrial quality spray gun such as a Binks 700 or Graco 205-591.

Fluid tip: large enough orifice to allow passage of solids without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Note that reversible tips are very helpful because of the speed with which clogs can be removed, and adjustable tips are beneficial for complex structures. This allows for the immediate changing of the spray pattern size (by changing the orifice size) at the spray gun. The smallest orifice diameter provides the best

atomization because the volume of paint is being forced through a smaller opening. The orifice size for vinyl butyral paints is generally kept in the 0.013" to 0.017" range.

Alternatively, there are "ball tips" available which combine two separate tips of the same orifice with different fan widths on the same ball. These tips provide a narrow fan for small surfaces and a wide fan for larger surfaces. Fan width tip combinations range from 2 - 4 in./6 - 8 in. up to 2 - 4 in./16 - 18 in.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too much of a restriction, while larger hoses may allow too much material to flow.

Hose lengths: there are generally no restrictions on the hose length for airless spray. However, less than 150 ft is preferred because a longer hose causes a pressure drop. If, for example, a 20:1 pump is being used and 1800 psi is required for proper atomization, the use of a very long hose may cause such a pressure drop at the gun that proper atomization is not possible. In such a case, a smaller tip (if possible) or a larger pump with a higher compression ratio would be necessary.

Spray pump: the spray pump should be capable of providing from 2000 psi to 2500 psi paint to the spray gun. This pressure is generally adequate for proper atomization of the butyral wash primer material. If tails in the spray pattern form, the pressure needs to be increased. If increasing the pressure does not solve the problem, then the tip is clogged or worn. Although the higher pressures are necessary to eliminate the tails, ideally the pressures should be kept as low as possible to reduce the velocity of the paint. This reduces splashing and provides a more uniform film.

7.0 Application

7.1 Ventilation/Safety - When painting in enclosed spaces, sufficient exhaust ventilation shall be provided to exchange the air with fresh air at a rate of 5000 CFM for each spray gun in operation.

7.1.1 Make periodic tests to assure that the vapors are not accumulating and that the enclosed spaces are safe from fire and explosion hazards. Use a calibrated explosimeter or organic vapor analyzer.

7.1.2 Verify that the spray personnel and others in the work area are wearing air-fed hoods or cartridge-type respirators suitable for use with vinyl butyral wash primer coating.

7.2 Ambient Conditions - The vinyl butyral wash primer formulation can be applied at ambient and surface temperatures between 35°F and 125°F. However, temperatures between 50°F and 100°F are preferred because lower temperatures can cause running and sagging of the film, while higher temperatures cause rapid flash-off of the solvents resulting in a "dry" film that does not flow or knit together.

7.2.1 Monitor the ambient conditions with a sling psychrometer and surface temperature thermometer every four hours or more frequently if extremes are being encountered.

- 7.2.2 Verify that the air temperatures are between 50°F and 100°F (minimum 35°F; maximum 125°F), the surface temperature is at least 5°F greater than the ambient dew point temperature, and the relative humidity is less than 90 percent.

7.3 Spray Technique

- 7.3.1 The coatings are applied using a single spray coat. Verify that standard good spray techniques are being used:
- a. The spray gun must be held perpendicular to the surface at all times as arcing will create erratic thicknesses and overspray/dryspray.
 - b. The gun-to-surface distance should be held constant (6 to 10 in. for conventional and 12 to 16 in. for airless) to avoid too heavy or dry a coat.
 - c. The trigger should be released at the end of each pass to avoid excessive film build.

8.0 Thickness

The pretreatment primer (DOD-P-15328) shall be spray applied at a coverage rate of 250 to 300 square feet per gallon. The thinnest coating that forms a continuous film is appropriate for this material.

Films over 1.0 mil dry film thickness do not develop good adhesion or adequate toughness. Accordingly, 0.3 to 0.5 mils dry film thickness or 3.0 to 5.0 mils wet film thickness should not be exceeded. At these thicknesses, the base metal will show through the greenish-yellow translucent coating as evidenced by uneven coloring. This uneven coloring is the normal appearance. Do not attempt to hide the base metal completely.

9.0 Inspection of Each Coat

It is important to examine the wash primer prior to application of the finish coats for film thickness and cleanliness. Insufficient or excessive film thicknesses can lead to poor adhesion after the subsequent coats are applied. Dirt or debris trapped within or between coats can lead to poor adhesion. Debris projecting through the film can serve to wick water through the coating directly to or close to the substrate.

- 9.1 Do not inspect the surface until the coating has dried and cured to the degree that it can support handling without damage.
- 9.2 Inspect for surface dirt or debris prior to the application of subsequent coats. If present, it must be removed.
- 9.3 Inspect the coating thickness using a nondestructive magnetic dry film thickness gage (over galvanized) or Eddy Current (aluminum, copper).
- 9.3.1 For the inspection of the vinyl butyral wash primer, a good visual impression can be made as in paragraph 8.0. For formal reporting, take a

minimum of 15 readings per 100 square feet of large flat surfaces (e.g. dam gate). The 15 readings should be made in five clusters of three readings each. Each cluster should cover a few square inches in size.

The number of readings on complex surfaces shall be significantly greater than those above for large flat surfaces. All locations of all complex surfaces must be measured as these are the areas that historically fail first due to insufficient or excessive paint coverage. The specific number of readings depends on the results obtained. Initially, a minimum of three readings for every 4 to 5 square feet should be made. If the readings continue to be satisfactory, the frequency can be reduced. If unsatisfactory, the frequency shall be increased.

All of the readings must be between 0.3 and 0.5 mils.

9.3.2 Report insufficient or excessive film thickness to a supervisor. Insufficient thickness can generally be corrected by the application of an additional coat to the deficient areas. The resolution of excessive film thickness depends on the continuity of the film.

9.4 Visually inspect each coat and the final system for runs, sags, holidays, pinholes, and overspray/dryspray.

9.5 Mark all defective areas for repair using chalk or a marker designated by a supervisor. Re-inspect the reworked areas in accordance with this procedure to assure final specification compliance.

10.0 Time Between Coats

The first finish coat shall be applied no sooner than one hour nor longer than 24 hours after the application of the pretreatment primer (DOD-P-15328).

There are no limitations regarding the minimum drying time between finish coats, provided that recoating does not cause running, sagging, or bleed through. Likewise, there are no restrictions on the maximum drying time between coats provided the surface is clean from grease, oil, and other debris. If the surface has weathered for a lengthy period (e.g., 6 months or longer) special roughening may be required as directed by a supervisor.

11.0 Record Keeping

It is crucial to be certain that all painting records (see Daily Inspection Checklist) are properly recorded and filed for each project. The painting record is the only written verification of what was actually done at the time. If questions arise later, the records will be the only source of information or clues as to the material, equipment, and atmospheric conditions at the time of surface preparation, coating application, and cure.

Vinyl Systems

1.0 Systems and Use

- 1.1 This inspection procedure is applicable to the following vinyl materials and Corps of Engineers systems:**

Vinyl Coatings: VZ-108, V-766, V-106, V-102, V-103

Corps Systems: 3, 3-A-Z, 4, 5-A-Z, 5-B, 5-F-Z, 5-B-Z, 5-C-Z, 5-D, 5-E-Z, 5-F, 5-G-Z, 5-H-Z, 5-J-Z

- 1.2 Specific properties and compatibility problems with some of the vinyl materials are as follows:**

V-766 and V-106

- a. Self-priming.**
- b. Requires high degree of surface cleanliness as it will not adhere to rust.**
- c. Will not adhere to wash primer.**
- d. Can be used as a multiple coat system by itself without the need for other materials.**
- e. Used as intermediate coat over VZ-108.**
- f. Air pollution version V-766 (AP) cannot be used over VZ-108.**
- g. Topcoat can be gray or white in color.**
- h. Cannot be used over oil or alkyd materials as lifting may occur.**

V-102 and V-103

- a. Used as finish coat only.**
- b. Will not adhere to steel.**
- c. Will not adhere to wash primer.**
- d. Will not adhere well to VZ-108; therefore V-766 intermediate is used.**
- e. Will not adhere to coatings other than vinyl.**
- f. The air pollution version V-102 (AP) cannot be used in conjunction with VZ-108.**

VZ-108d

- a. Used as primer only.
- b. Requires clean steel for proper adhesion and performance.
- c. Cannot be topcoated with air pollution (AP) grades.

2.0 General Requirements for Inspections

- 2.1 Wear proper protective clothing including clean gloves to preclude contamination of the surfaces to be inspected.
- 2.2 Assure that proper lighting and adequate accessibility to areas to be inspected have been provided.
- 2.3 Conduct inspections in a planned and controlled manner in accordance with this inspection plan. Divide large areas into smaller segments to organize structures for proper inspection coverage.
- 2.4 Document the results of all inspections on the Daily Painting Inspection Report Form.
- 2.5 Use inspection instrumentation in accordance with the Use and Calibration of Inspection Instrumentation procedure in Appendix C.

3.0 Continuous Inspections

The following inspections are performed during all phases of the blast cleaning and painting work, and as such, are termed continuous inspections.

3.1 Protective Coverings

Blast cleaning dust, abrasives, and paint overspray can damage or impair the operation of certain equipment and structures in the work area. Therefore, protective coverings must be properly installed and remain intact.

- 3.1.1 Prior to blast cleaning/coating application in a given area, inspect to assure that galvanized, stainless steel surfaces, bearings, gages, previously completed coating work, and any other items designated by the supervisor, have been suitably masked and protected from the coating operations.
- 3.1.2 Spot-check all masking during work to assure that it remains intact. If the masking is loosened or removed, notify the contractor so that repairs can be made immediately.

3.2 Ambient Conditions

If moisture condenses on a prepared steel surface, corrosion will result prior to the application of the protective coating. Also, moisture condensation on a coating prior to sufficient solvent release can affect its curing. Insufficient or excessive air and surface temperatures during application can lead to the entrapment of solvents or the formation of a dry paint film that does not knit and

man" controls which will shut off the abrasive flow in the event the nozzle is dropped. The hose sections must be connected using external couplings that are locked together with wires. The blasters must be supplied with air-fed hoods that comply with MESA and air purity requirements. Other personnel in the blasting area must use dust masks.

4.2 Sharp Edges and Weld Spatter

Sharp edges and weld spatter are detrimental to coating performance as the coating will draw thin on these areas to provide insufficient protection. In addition, weld spatter can become dislodged in service, removing the coating with it.

4.2.1 Inspect for the removal of sharp edges, weld spatter, and laminations to the extent necessary to provide a surface suitable to receive protective coatings. This generally necessitates the removal of all weld spatter and the rounding of edges to a radius of approximately 1/16 to 1/8 in. Welds need not be ground smooth or flush.

4.2.2 Report any questionable areas to a supervisor for resolution. This includes the presence of pits with sharp edges.

4.3 Grease and Oil

Deposits of grease or oil on the surface must be removed prior to preparation so that they are not impacted into the surface or spread onto areas which have already been prepared. Grease or oil will interfere with the adhesion of the coating.

4.3.1 Prior to blast cleaning, inspect for any deposits of grease or oil. If found, the area shall be solvent cleaned in accordance with SSPC-1. Solvent cleaning requires the frequent use of new clean cloths and clean solvent to assure that the contaminant is removed, rather than simply spread across the surface.

4.3.2 After cleaning, visually reinspect the areas to ensure that the grease and oil have been removed.

4.4 Nozzle Pressure

Adequate blast pressure at the nozzle is important for productivity. The optimum blasting pressure at the nozzle is 90 to 100 psig. If the pressure drops to 60 psig, the productivity is decreased by 50 percent. Excessive pressures can also be detrimental, as the abrasives may be fractured prior to reaching the surface, eliminating its effectiveness. In addition, excessive pressures can lead to greater operator fatigue. Note that the blasting pressure has a greater impact on productivity than quality, as the same degrees of surface cleanliness and roughness (profile) can be achieved with lesser pressures.

4.4.1 During the initial start-up of the job, record the pressure of the air used for blast cleaning. Take the pressure as close to the blast nozzle as possible using a hypodermic needle pressure gage. Insert the needle through the hose in the direction of the nozzle and record the reading

with abrasive flowing. When taking a reading, all nozzles as well as other pneumatic equipment associated with the compressor system should be operating.

- 4.4.2 This reading need only be taken at the beginning of a project or when changes are made in the compressed air system.

4.5 Abrasive Cleanliness/Profile

Clean, dry abrasive is essential for achieving quality work. An oily abrasive will contaminate the surface and a damp abrasive will clog blast pots in addition to creating flash rusting.

The surface roughness or profile of the steel after blast cleaning is also important in that it assures proper adhesion of the coating system. An insufficient profile can lead to peeling or disbonding of the coating system, while an excessively heavy or deep profile can result in pinpoint rusting caused by peaks of the steel extending through the coating system. The surface profile after blast cleaning should normally range from 1.0 to 3.0 mils. This roughness can generally be accomplished by a medium-fine mesh sand. Note that steel abrasives will have a tendency to create a much rougher, irregular profile and cause "hackles" or sharp projections of steel in the surface which are difficult to properly coat with thin film vinyl systems. Such hackles can lead to pinpoint rusting. Note also that if soft abrasives are used, they may "powder" onto the surface and as such become a very weak contaminant that can affect coating adhesion. Soft abrasives may also contain clay which can lead to blistering of the coating in immersion service.

- 4.5.1 Visually check the abrasive for dryness and contaminants. If the abrasive is damp or contains numerous particles other than the abrasive material itself, it should not be used.
- 4.5.2 Measure and record the surface profile of the blast-cleaned steel using the Keane-Tator Surface Profile Comparator or Testex Press-O-Film tape. Each measurement is the average of three profile readings within the area of 1 square foot. Record the profile for every 500 square feet of surface area.
- 4.5.3 At least twice daily visually verify that the abrasive gradation is correct. At the beginning of the job, retain a sample of the abrasive that provides the proper surface profile and use it as a standard of comparison. If samples taken in the field appear to be smaller or larger than the control sample or if the surface profile changes, report the discrepancy to a supervisor.
- 4.5.4 If abrasive is recycled, make certain that it is a steel abrasive or other type which is capable of being recycled. Sand shall not be reused.

Inspect a sample of the abrasive for oil and grease contamination a minimum of twice daily. Drop a handful of the recycled abrasive into a vial of water (approximately 1 pint) and shake vigorously. The abrasive should not be used if oil is visible on the surface of the water.

4.6 Surface Cleanliness

A high degree of surface cleanliness is necessary for the proper adhesion and performance of vinyl systems. Rust, mill scale, old paint, grease, or oil will interfere with the adhesion and performance of the systems. Touching the steel with bare hands can also affect paint performance as the oils and salts from the skin can cause blistering if painted over. Greasy, oily gloves must also not be allowed to contact the cleaned surface.

- 4.6.1 The surfaces shall be blast cleaned to a degree of cleanliness "approaching White Metal". In order to determine compliance with this degree of cleaning, mentally divide the structure into squares approximately 6 in. on a side. Seventy-five percent of the squares shall be free of all rust, mill scale, or staining (e.g., White Metal). The remaining 25 percent of the squares are permitted to contain very slight shadows, stains, or discolorations resulting from very thin, adherent, sparsely scattered residues of mill scale or corrosion products. However, on surface irregularities such as edges, interior angles, welds, rivet lines, junctions of joining members, and pits, the White Metal grade of cleaning shall be strictly enforced.
- 4.6.2 Inspect 100 percent of the cleaned surface for compliance with the above and pay particular attention to rivet heads, backside of angles, and inaccessible areas, as these are historically the most poorly prepared. If necessary, use a mirror to view these areas.
- 4.6.3 Inspect with the unaided eye. However, a five-power hand magnifier may be used as required to verify surface cleanliness.
- 4.6.4 Inspect the surface from various angles to assure that the angle of incidence of the profile is not hiding areas of rust or mill scale or alternatively, that shadows caused solely from the angle of profile are not rejected.
- 4.6.5 During the inspection, reexamine the surface for the presence of sharp edges, weld spatter, or additional laminations uncovered by abrasive blasting. Report them immediately to a supervisor for resolution.
- 4.6.6 Mark areas for rework that are not in conformance with the specification requirements. Use only those marking devices agreed upon or permitted by the specification or supervisors (e.g., chalk). Do not use wax crayons as the vinyl will not adhere if it is not completely removed during the rework.
- 4.6.7 Reinspect the deficient areas after rework for specification compliance. In addition, spot check previously acceptable areas to assure that flash rusting has not occurred. Continue to mark and re-inspect deficient areas until the surface is within specification requirements. Record the final condition of the surface.
- 4.6.8 When commencing work on areas adjacent to those previously coated, care must be taken to direct the blast nozzle away from the recently

painted surfaces. Overblast from the nozzle will damage the previously coated areas. Such damage will often not be detected by a casual visual inspection, but will result in pinpoint rusting when placed in service.

In addition, the blast nozzle pressure may cause the coating to lift at the edge. Subsequently applied vinyl coating material will not flow under and seal this loose edge.

Because of these inherent problems at overlap areas, it is desirable, if possible, to conclude a days' work at a corner or natural break in the structure.

4.7 Cleanliness Prior to Coating

The cleaned steel must be free from corrosion prior to coating application, otherwise the benefits of thorough blast cleaning are lost. Such interference material will impair coating adhesion and can serve to wick moisture through the coating directly to the steel.

4.7.1 Inspect the surfaces prior to coating application to assure that abrasive residues have been removed and that the surface is free from dirt, dust or other debris. Pay specific attention to corners and inaccessible areas for pockets of abrasive that may remain. In addition, be certain that the scaffolding has been thoroughly blown down to remove pockets of dust or abrasive which could be dislodged during the coating operation. The dust cleanliness at this point is even more critical if airless spray is to be employed, since the airless gun cannot be used to blow down the surface prior to application, as is the case with a conventional gun.

4.7.2 The prepared surfaces shall be painted within 8 hours after cleaning and prior to the formation of flash rusting. During the cleanliness inspection, pay special attention to assure that flash rusting has not occurred. If present, mark for removal or to be isolated from painting. If isolated from painting, assure that it is recleaned and painted at a later time. The recleaning shall involve blast cleaning, as power tools tend to polish the surface, providing an unacceptable smoothness for adhesion of the vinyl coating.

5.0 Mixing and Thinning

Mixing - Thorough mixing of the vinyl materials is essential to assure that pigments have not settled out into the bottom of the containers and that a homogenous blend results. This is extremely critical for the materials which contain zinc, abrasive, or the Glassflake additive package. Improper mixing of these materials will allow the erratic deposition of the particular additive throughout the applied film. This results in agglomerations of the additive which can create voids, pinholes, and localized areas of high moisture permeability.

Thinning - The thinning requirements for the various materials are provided along with the mixing instructions below. Note that different thinners are recommended for different temperature ranges. The temperature ranges are not absolute, but should be considered as guidelines only, as it is not critical that the thinners be changed as soon as a certain temperature is reached. Conceptually, the reason for changing thinners is that as the temperatures increase, the speed at which the

AD-A168 486

GUIDE FOR INSPECTION OF COATINGS APPLIED TO HYDRAULIC
STRUCTURES(U) CONSTRUCTION ENGINEERING RESEARCH LAB
(ARMY) CHAMPAIGN IL A BEITELMAN ET AL. APR 86

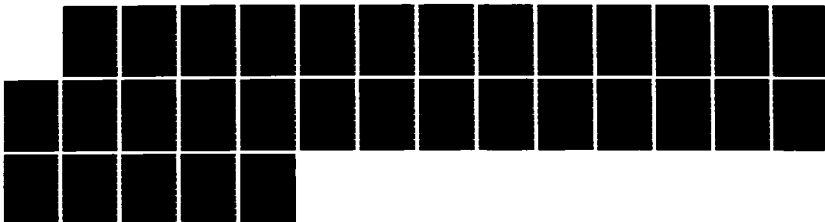
3/3

UNCLASSIFIED

CERL-TR-M-86/09

F/G 13/2

NL





MICROCOPY

CHART

thinners evaporate also increases. Thus, it can be difficult to apply a continuous wet film due to such rapid evaporation. Different types of thinners have different rates of evaporation, and therefore, at higher temperatures a "slower" thinner assists in the application of a film which remains wet longer. Conversely, "faster" thinners are used at lower temperatures to decrease the "wet time" and reduce the possibility of runs, sags, and solvent entrapment.

If a good wet coat is not applied, it does not flow together properly and results in porosity and poor adhesion to the steel and to underlying coats.

- 5.1 Assure that adequate ventilation has been provided in the mixing area. All mixing buckets and paddles must be clean of old paint and debris. Otherwise, the new paint can become contaminated.
- 5.2 Inspect the material delivered to the mixing site for coating type and condition of cans. Leaky containers or containers showing corrosion on the inside should be rejected and reported to a supervisor as they indicate potential problems.
- 5.3 Material which has exceeded its shelf life should be segregated from use and reported to a supervisor. The shelf life of the vinyl materials is generally 9 months to 1 year. Older material is most likely satisfactory; however, samples must be sent to USA-CERL laboratory for recertification prior to use.
- 5.4 If the material is gelled upon opening, it can be heated to 120°F in an attempt to break the gel. If it breaks and can be homogenously mixed, the material is acceptable.
- 5.5 Record the batch numbers of the material. Observe and record the mixing and thinning procedures and amounts. It is best to have all materials at room temperature prior to thinning to better control the viscosity. Recommended thinner amounts are presented in Section 5.8.; they should provide a viscosity of approximately 40 seconds with a #4 Ford cup for conventional spray, and 50 seconds for airless (50 seconds and 70 seconds respectively with a Zahn #2 cup).
- 5.6 The pot life of the vinyl materials (with the exception of VZ-108) is equivalent to the shelf life, provided the containers are tightly sealed after use to prevent evaporation of volatile material. Although the pot life of the vinyl systems containing the abrasive or additive packages is also equivalent to the shelf life, it may be nearly impossible to completely remix all of the abrasive or additive after it has settled for weeks. Therefore, the vinyl materials using the abrasive or additive packages should be used as quickly as possible. For VZ-108, the pot life can be as long as 8 days after mixing if the paint is kept tightly covered at all times. On the other hand, if an increase in viscosity is noted, the material should not be applied.
- 5.7 After mixing, inspect the bottom of the containers to ensure that no lumps or settlement remain.

5.8 Specific Mixing Instructions

VZ-108 Vinyl Zinc

This material consists of three parts: Component A-Base (4.5 gallons), Component B-Silane (3 fluid ounces), and Component C-Zinc Dust (27.5

pounds). Thoroughly power stir the base paint (Component A) and add Component B and blend together. While agitation continues, slowly sift the zinc dust (Component C) into the mixture and continue power agitation until the zinc dust has been thoroughly dispersed. The speed of mixing need only be rapid enough to blend the material together, but not so rapid as to entrain air into the paint. Prior to use, strain the mixture through a 30-60 mesh screen to prevent zinc dust slugs from reaching the spray gun nozzle.

Thinning is normally not required when the ambient temperatures are less than 80°F. However, if thinning is required at less than 80°F to provide a wet spray coat, up to 1 pint per gallon methyl isobutyl ketone (MIBK) can be added. If airless spray is used, methyl ethyl ketone (MEK) can be substituted for the MIBK. For temperatures above 80°F, methyl isoamyl ketone (MIAK) should be used. It is essential that agitation be continued during all spraying to keep the powder from settling to the bottom of the spray pot. Because of the settlement potential, pot agitation shall not be interrupted. The speed of agitation need only be enough to keep the zinc in suspension, but not so fast as to entrain air into the mixed paint.

V-766, V-106, V-102, and V-103

Thoroughly mix the material by hand or power stirring until all settlement in the bottom of the container is uniformly blended into the material. As an alternative, after the solids have been lifted from the bottom of the container, the material can be "boxed" between two cans until a homogenous blend results. Thinner should be added as recommended below for the approximate temperature ranges.

Below 50°F - up to 25 percent MEK

50°F-70°F - up to 25 percent MIBK*

Above 70°F - up to 40 percent MIAK

*If airless spray is used, MEK instead of MIBK can be used.

If the material contains the "AP" suffix, the thinners shall be as follows:

Below 50°F - up to 25 percent ME-80 of MEK

Above 50°F - up to 25 percent NP-10

V-766 and V-106 Modified with Abrasive

The mixing of the base material is identical to that described above except that only power mixing shall be used. After thorough mixing of the liquid component, add either Alundum, 94% aluminum oxide, Size No. 500, abrasive grains (Norton) or Size No. 250 Garnet Abrasive (Idaho Garnet Abrasive Company) just prior to application. The proportion is 1 pound abrasive to 1 gallon of unthinned vinyl. Thoroughly blend together and maintain constant

agitation during application. Thinner additions shall be as defined above and only conventional spray shall be used, as it is not capable of passing through the airless spray tip.

Note that any interruption of agitation allows the abrasive grit to drop to the bottom of the container rapidly. Such settlement of the abrasive can occur by the time the material is transferred to the spray pot. Therefore, it is recommended that the final mixing be accomplished in the spray pot itself so that the pot agitator can be used to keep the abrasive in suspension.

V-766, V-106, and V-103 with Glassflake Additive Package (Formula V-113)

The additive package comes as a standard 2-gallon kit for addition to 5 gallons of the base liquid. Thoroughly power mix 5 gallons of the base until a homogenous blend results. Add the 2-gallon additive package and continue power mixing until the additive is uniformly dispersed. Thinner can be added as follows:

Below 50°F - up to 18 percent MEK

50°F-70°F - up to 18 percent MIBK

Above 70°F - up to 18 percent MIAK

If the material contains the "AP" suffix, the thinners shall be as follows:

Below 50°F - up to 18 percent ME-80

Above 50°F - up to 18 percent NP-10

The additive has a tendency to settle out into the bottom of the container. Therefore, constant agitation during application is necessary to keep the additive in suspension. Also, in order to eliminate the settlement of the additive between the time of mixing and spraying, it is helpful to do the final mixing in the spray pot so that the agitator in the pot can be used immediately to keep the material in suspension. Only conventional spray can be used for this material, as it is not capable of passing through the airless spray tip.

6.0 Application Equipment

- 6.1 Vinyl paint shall be spray applied, except that areas inaccessible to spraying may be brushed. Conventional spray is *preferred* over airless as airless has a tendency to entrap solvent and air within the paint film, resulting in pinholing and blistering. Conventional spray is *mandatory* for any of the formulations containing the abrasive additive or the formula V-113 Glassflake additive package.
- 6.2 Record the type of application equipment used, including the manufacturer, identification of tips, needles, nozzles, hose sizes and lengths, and so forth.
- 6.3 The following spray equipment is suitable for the application of the vinyl coatings, although equivalent equipment can be substituted. The application equipment shall be kept clean and in good mechanical condition.

Conventional Spray--Vinyl Formulations Without Glassflake Additive

Spray gun: industrial quality gun such as Binks 18 or DeVilbiss MBC or JGA.

Fluid tip: large enough orifice to allow passage of solids and zinc powder without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Suitable tips are Binks 66 or DeVilbiss E.

Air cap: sized with sufficient air openings to atomize the paint stream without so many openings to cause excessive solvent evaporation prior to deposition of the paint film. Suitable caps are Binks 66 PE or 63 PB or DeVilbiss 704, 715, 78 or 765.

Air hose: 5/16 in. ID provides the proper volume of air.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too great a restriction, while larger hoses allow too much material to flow and compound the pigment settling problem in vinyl zinc and abrasive additive formulations.

Hose lengths: less than 150 ft is preferred with 50 to 100 ft common. The hoses should be as short as possible. Longer hoses allow the solids to settle in the line prior to reaching the spray gun. This leads to clogging and the application of nonhomogenous films.

Atomization pressure: only enough air pressure to atomize the paint without creating dryspray; usually 50 to 60 psi at the gun.

Spray pot: the spray pot must be equipped with an agitator for the VZ-108 (zinc) formulation and those containing the abrasive additive. It is not necessary for the regular formulation.

Conventional Spray--Vinyl Formulations With Glassflake Additive

Spray gun: industrial quality gun such as Binks 18 or DeVilbiss MBC or JGA.

Fluid tip: large enough orifice to allow passage of the Glassflake additive without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Suitable tips are Binks 66 or 67 or DeVilbiss D or E.

Air cap: sized with sufficient air openings to atomize the paint stream without so many openings to cause excessive solvent evaporation prior to deposition of the paint film. Suitable caps are Binks 63 PB or 206 or DeVilbiss 704 or 765.

Air hose: 5/16 in. ID provides the proper volume of air.

Material hose: 3/8 to 1/2 in. ID allows for the proper feed of the material. Smaller hoses create too great a restriction, while larger hoses allow too much material to flow. Since larger hoses contain more volume, the settling problem inherent with heavily filled materials such as Glassflake is aggravated.

Hose lengths: less than 150 ft is preferred with 50 to 100 ft common. The hoses should be as short as possible. Longer hoses allow the Glassflake additive to settle in the line prior to reaching the spray gun. This leads to clogging and the application of nonhomogenous films.

Atomization pressure: only enough air pressure to atomize the paint without creating dryspray; usually 50-70 psi at the gun.

Spray pot: the spray pot must be equipped with an agitator to prevent the Glassflake additive from settling to the bottom of the spray pot.

Conventional Hot Spray

The advantage of hot spray is that less thinner is necessary and it is ideal for low temperature application, as the higher material temperatures considerably reduce the viscosity of the material. The material temperature should be maintained below 170°F with 160°F quite common. The material circulation should also be maintained at a low rate in order to avoid excessive use of the heater. It is essential that the hose lengths be kept to a minimum and preferably below 100 feet. The insulation should be continually inspected to assure that it is not excessively damaged.

Airless spray--Vinyl Formulations Without Abrasive or Glassflake Additive

Airless spray is permitted for use, but note that the use of conventional spray is strongly recommended for the vinyl systems. This is because airless spray has a tendency to entrap air and solvent in the paint film, creating blisters and pinholes. Much of this can be avoided by the use of conventional spray because the solvent has a better opportunity to evaporate from the atomized droplets as air mixes with the paint at the spray gun. Historically, many more quality problems have resulted from the use of airless spray versus conventional for these materials.

Spray gun: industrial quality spray gun such as a Binks 500.

Fluid tip: large enough orifice to allow passage of solids and zinc powder without clogging, but not so large as to prohibit atomization of the paint stream into fine droplets. Note that reversible tips are very helpful because of the speed with which clogs can be removed, and adjustable tips are beneficial for complex structures. This allows for the immediate changing of the spray pattern size (by changing the orifice size) at the spray gun. The smallest orifice diameter provides the best atomization because the volume of paint is being forced through a smaller opening. The orifice size for vinyl paints is generally kept to 0.015 to 0.017 in. maximum.

Alternatively, "ball tips" are available which combine two separate tips of the same orifice with different fan widths on the same ball. These tips provide a narrow fan for small surfaces and a wide fan for larger surfaces. Fan width tie combinations range from 2-4 in./6-8 in. up to 2-4 in./16-18 in.

Material hose: 3/8 in. ID allows for the proper feed of the material. Smaller hoses create too much of a restriction, while larger hoses may allow too much material to flow.

Hose lengths: there are generally no restrictions on the hose length for airless spray. However, less than 150 ft is preferred because a larger hose causes a pressure drop. If, for example, a 20:1 pump is being used and 1800 psi is required for proper atomization, the use of a very long hose may cause such a pressure drop at the gun that proper atomization is not possible. In such a case, a smaller tip (if possible) or a larger pump with a higher compression ratio would be necessary.

Spray pump: the spray pump should be capable of providing from 2000 psi to 3000 psi paint to the spray gun. This pressure is generally adequate for proper atomization of the vinyl materials. If tails in the spray pattern form, the pressure needs to be increased. If increasing the pressure does not solve the problem, then the tip is clogged or worn. Although the higher pressures are necessary to eliminate the tails, ideally the pressures should be kept as low as possible to reduce the velocity of the paint. This reduces splashing and provides a more uniform film.

7.0 Application

7.1 Ventilation/Safety - When painting in enclosed spaces, sufficient exhaust ventilation shall be provided to exchange the air with fresh air at a rate of 5000 CFM for each spray gun in operation.

7.1.1 Make periodic tests to assure that the vapors are not accumulating and that the enclosed spaces are safe from fire and explosion hazards. Use a calibrated explosimeter or organic vapor analyzer.

7.1.2 Verify that the spray applicators and other personnel in the work area are wearing air-fed hoods or cartridge-type respirators suitable for use with vinyl coatings.

7.2 Ambient Conditions - The vinyl formulations can be applied at ambient and surface temperatures between 35° and 125°F. However, temperatures between 50°F and 100°F are preferred because lower temperatures can cause running and sagging of the film and the entrapment of solvents, while higher temperatures cause rapid flash-off of the solvents resulting in a "dry" film that does not flow or knit together. In either case, it is difficult to achieve a pinhole-free film that is suitable to withstand immersion service.

7.2.1 Monitor the ambient conditions with a sling psychrometer and surface temperature thermometer every 4 hours or more frequently if extremes are being encountered.

7.2.2 Verify that the air temperatures are between 50°F and 100°F (minimum 35°F; maximum 125°F), the surface temperature is at least 5°F greater than the ambient dew point temperature, and the relative humidity is less than 90 percent.

7.3 Agitation - During application, constant agitation is *mandatory* for VZ-108 and the formulations containing the abrasive or Glassflake additive package, otherwise the solids will settle out. Agitation is not necessary for the other vinyl formulations.

7.3.1 Verify that an agitator is in operation during the use of the vinyl zinc or additive formulations.

7.3.2 If spraying is resumed after any interruption of longer than 15 minutes, verify that the entire length of the material hose is whipped vigorously to redisperse any settled zinc or additive.

7.3.3 If the painting operation is to be suspended for more than an hour, verify that the paint is emptied from the material hose and maintained under constant agitation.

7.4 Spray Technique

7.4.1 The coatings are applied using either a double spray coat (all materials except those containing Glassflake additive) or a single spray coat (those containing the additive). For either of the methods, verify that standard good spray techniques are being used:

a. The spray gun must be held perpendicular to the surface at all times as arcing will create erratic thicknesses and overspray/dryspray.

b. The gun-to-surface distance should be held constant (6 to 10 in. for conventional and 12 to 16 in. for airless) to avoid too heavy or dry a coat.

c. The trigger should be released at the end of each pass to avoid excessive film build.

7.4.2 Double Spray Coat - Verify that each coat of the vinyl materials (with the exception of those containing the Glassflake additive package) are applied as a double spray coat. This double spray operation (per coat) consists of a preliminary extra pass on edges, corners, angles, seams, crevices, weld lines, and similar surface irregularities. Such irregularities shall be sprayed from every direction in order to assure complete coverage of all surfaces. After the preliminary spray pass, the paint shall be applied to a working area of not less than several hundred square feet in a single pass (50 percent overlap per pass) followed after drying to at least a tack-free condition by another spray pass (50 percent overlap per pass) applied at right angles to the first (whenever possible). This "cross hatch" technique helps to even-up coating thicknesses and to ensure that there are no skips or misses. This entire operation represents one double spray coat.

Regardless of the formulation applied, pits, cracks, and crevices shall be filled with paint insofar as practicable (without detrimental pinholes), but in any event all pit surfaces shall be thoroughly covered and all cracks and crevices sealed off against the entrance of moisture.

- 7.4.3 Single Spray Coat -** Verify that each coat of the vinyl materials containing the Glassflake additive package are applied as a single 50 percent) overlap pass, with the preliminary extra pass on irregularities as described above.

8.0 Thickness and Coverage

Table B2 identifies the coating materials to be used for each Corps of Engineers painting system, the coverage rate per coat, number of coats to be applied, and approximate thickness per coat. Note that each of the systems is designed to be fast drying, so that subsequent coats can be applied very quickly provided running, sagging, solvent entrapment, or pinholing does not occur. This makes it possible to apply an entire system in one day.

9.0 Inspection of Each Coat

It is important to examine each coat prior to application of the next for film thickness and cleanliness. Insufficient film thicknesses per coat can lead to pinpoint rusting prior to application of the next due to the presence of exposed peaks of the surface profile. This is particularly critical for the first or second coats if subsequent coats are not to be applied until a day or more later. Excessive film builds per coat can result in solvent entrapment and the formation of pinholes, both of which increase the moisture permeability of the paint system. Dirt or debris trapped within or between coats can lead to poor adhesion and blistering in service. Debris projecting through the film can serve to wick water through the coating directly to or close to the substrate.

- 9.1** Make certain that all coats are being applied in the proper sequence and color. Table A2 provides this information for all systems.
- 9.2** Do not inspect the surface until the coating has dried and cured to the degree that it can support handling without damage.
- 9.3** Inspect for surface dirt or debris prior to the application of subsequent coats. If present, it must be removed.
- 9.4** Report the presence of pinpoint rusting to a supervisor for resolution. Minor localized areas may be repaired by hand sanding followed by application of the material. Larger areas may require complete blast cleaning.
- 9.5** Inspect the coating thickness using a nondestructive magnetic dry film thickness gage.
- 9.5.1** Perform only a cursory thickness inspection between coats to minimize the time spent on the coating to avoid unnecessary contamination. Note that if the vinyl is soft or tacky, a reasonably accurate measurement will not be possible as the instrument probe will deform the coating or "stick" during pull-off type measurements (e.g., Mikrotest). Therefore, if it is necessary to measure the thickness at a time when the vinyl is still slightly soft (in order to permit the next coat to be applied), a plastic shim of known thickness can be placed between the instrument magnet and the vinyl paint. Subtracting the thickness of the shim from the total measurement will allow a reasonably accurate assessment of the coating thickness. Table B2 provides guidelines for the thickness of each coat.

These guides are not absolute requirements, but they help ensure that the total system thickness and continuity requirements will be achieved.

- 9.5.2 For the inspection of the complete system, take a minimum of 15 readings per 100 square feet of large, flat surfaces (e.g., dam gate). The 15 readings should be made in five clusters of 3 readings each. Each cluster should cover a few square inches in size. The number of readings on complex surfaces shall be significantly greater than those for large, flat surfaces. All locations of all complex surfaces must be measured as these are the areas that historically fail first due to insufficient or improper paint coverage. The specific number of readings depends on the results obtained. Initially, a minimum of three readings for every 4 to 5 square feet should be made. If the readings continue to be satisfactory, the frequency can be reduced. If unsatisfactory, the frequency shall be increased.

The average of all of the readings must be at least as heavy as the thicknesses indicated under "Total" in Table B2 for the particular system being applied. Single clusters can measure as low as the "minimum" value provided in the same Table B2. Any readings less than the "minimum" are unacceptable.

- 9.5.3 Report insufficient or excessive film thickness to a supervisor. Insufficient thickness can generally be corrected by the application of an additional coat to the deficient areas. The resolution of the excessive film thickness depends on the continuity of the film. This can be determined by using a razor blade to shave away the coating and examine for the presence of voids. If voids or pinholes are detected, partial or complete coating removal may be required.
- 9.6 Visually inspect each coat and the final system for runs, sags, holidays, pinholes, and overspray/dryspray. Note the purpose of the vinyl paint is for protection, and therefore a void-free film is necessary. Runs or sags which do not contain pinholes or voids normally need not be removed.
- 9.6.1 A holiday detector may be useful in assisting in the final system inspection for the presence of holidays, excessively thin areas (e.g., on edges and weld lines), voids, and pinholes. Note however, that such instruments may give erroneous results when used in conjunction with electrically conductive aluminum pigmented coatings. In this case, test trials of the equipment are recommended. If conductivity proves to be a problem, the testing could be done prior to the application of the aluminum finish.
- 9.6.2 The use of the holiday detector is described in the instrument section of the procedures, but basically it uses a wetted sponge electrode which is grounded to the surface through the detection unit. The sponge is passed across the surface and the water penetrates pinholes or flaws in the coating system to complete a circuit. A bell or buzzer rings each time a flaw is encountered.
- 9.7 Mark all defective areas for repair using chalk or a marker designated by a supervisor. Reinspect the reworked areas in accordance with this procedure to assure final specification compliance.

10.0 Curing Prior to Service

Monitor the ambient conditions after application of the final coat to assure that the material is properly cured prior to service. Vinyl paints dry through solvent evaporation. The coating will remain weak and subject to damage by abrasion if solvent remains. A minimum of 3 days of curing at average temperatures of 65°F and above are necessary. For average temperatures below 65°F, additional dry time may be necessary, as the solvents evaporate slower at low temperatures. For colder temperatures, consult a supervisor.

10.1 Since drying times prior to placing the structure in service are computed from the day the final coat is applied to a given area, it is desirable to apply the total system to a given area prior to moving on to the next.

10.2 Since it is difficult to verify that solvents have completely evaporated, even after 3 days of cure, it is recommended that areas subject to immersion or particularly abrasive action (such as the skin plate) on a structure be cleaned and totally coated first in the sequence of work. This will permit these "high wear" areas to have the greatest dry time prior to service.

11.0 Record Keeping

It is crucial to be certain that all painting records (see Daily Inspection Checklist) are properly recorded and filed for each project. The painting record is the only written verification of what was actually done at the time. If questions arise later, the records will be the only source of information or clues as to the material, equipment, and atmospheric conditions at the time of surface preparation, coating application, and cure.

Table B2

Vinyl System Thickness and Number of Coats

System	Mat'l	Coverage Per Coat (sq ft/gal)	Number of Double Spray Coats†	Thickness Per Double Spray Coat (mils)**
3	V-766*	300	2	1.5-2.0
	V-102*	300	2	1.5-2.0
	Total	N/A	4	6.0 (min. 5.0)
*First coat white; second coat gray; third and fourth coats aluminum.				
3-A-Z	VZ-108	300	1	2.5
	V-766*	300	1	1.5-2.0
	V-102*	300	1 or 2	1.0-2.0
	Total	N/A	3 or 4	6.0 (min. 5.0)

*V-766 is white and the final V-102 coats aluminum.

Table B2 (Cont'd)

System	Mat'l	Coverage Per Coat (sq ft/gal)	Number of Double Spray Coats†	Thickness Per Double Spray Coat (mils)**
4	V-766*	300	5	1.5-2.0
	Total	N/A	5	7.5 (min. 6.0)
*The first and third coats are white; the second, fourth, and fifth are gray.				
5-A-Z	VZ-108	300	1	2.5
	V-766*	300	1	1.5-2.0
	V-103*	300	2	1.5-2.0
	Total	N/A	4	6.5 (min 5.0)
*V-766 is white and the third V-103 coat black.				
5-B	V-106*	300	1	1.0-2.0
	V-106 with abrasive*	N/A	4	<2.0
	Total	N/A	5	7.5 (min. 6.0)
*System begins with dark red and alternates with light red. Dark red is the final color.				
5-B-Z	VZ-108	300	1	2.5
	V-106 with abrasive*	N/A	3	<2.0
	Total	N/A	4	7.5 (min. 6.0)
	*The V-106 begins with dark red, alternates with light red, and ends with dark red.			
5-C-Z	VZ-108	300	1	2.5
	V-106*	300	3	1.5-2.0
	Total	N/A	4	7.0 (min. 5.5)
*V-106 begins with dark red, alternates with light red, and ends with dark red.				
5-D	V-106*	300	5	1.5-2.0
	Total	N/A	5	7.5 (min. 6.0)
*V-106 begins with dark red, alternates with light red, and ends with dark red.				
5-E-Z	VZ-108	300	1	2.5
	V-766*	300	3	1.5-2.0
	Total	N/A	4	7.0 (min. 5.5)
*V-766 first and final coats are gray; the middle coat is white.				

Table B2 (Cont'd)

System	Mat'l	Coverage Per Coat (sq ft/gal)	Number of Double Spray Coats‡	Thickness Per Double Spray Coat (mils)**
5-F	V-766*	300	1	1.0-2.0
	V-766 with abrasive*	300	4	<2.0
	Total	N/A	5	7.5 (min. 6.0)
*System begins with gray vinyl and alternates with white. Gray is the final color.				
5-F-Z	VZ-108	300	1	2.5
	V-766 with abrasive*	300	3	<2.0
	Total	N/A	4	7.5 (min. 6.0)
*V-766 first and final coats are gray; the middle coat is white.				
5-G-Z	VZ-108	300	1 Double Spray	2.5
	V-766 with Glassflake package*	400	3 Single Spray	1.5-2.0
	Total	N/A	4	7.5 (min. 6.0)
*The first V-766 coat with the additive package is white; second and final coats are gray. V-766 with Glassflake is applied as a single spray coat.				
5-H-Z	VZ-108	300	1	2.5
	V-106 with Glassflake package*	400	3 Single Spray	1.5-2.0
	Total	N/A	4	7.5 (min. 6.0)
*The first coat of V-106 is dark red, second coat light red, and final coat dark red. V-766 with Glassflake is applied as a single spray coat.				
5-J-Z	VZ-108	300	1	2.5
	V-103 with Glassflake package	400	3 Single Spray	1.5-2.0
	Total	N/A	4	7.5 (min. 6.0)

‡V-766 and V-106 with Glassflake are applied as single spray coats.

**CW-09940 requires that extra coats be applied where necessary to achieve thickness requirements.

APPENDIX C:

USE AND CALIBRATION OF INSPECTION INSTRUMENTATION

1.0 General

- 1.1 Each instrument shall have a unique serial number.
- 1.2 If an instrument is found to be out of calibration, reevaluate all data obtained by the instrument since the last calibration. If the corrected results do not affect the end quality (for example, recording 2.5 mils of zinc when the instrument should have registered 3.0 mils, which is still within specified tolerances), draw a line through the old value, record the corrected value, and note the reason for the correction on each form. If the corrected results will affect the end quality, rework will be required.

2.0 Calibration and Use

2.1 Sling Psychrometer

Description: wet and dry bulb thermometers attached to a single handle or cord.

2.1.1 Calibration

- a. Psychrometers are factory calibrated. Field calibration is not necessary.
- b. The thermometers should maintain their accuracy under normal use.
- c. Verify the accuracy of the thermometers at least monthly.
- d. Compare three thermometers (remove the wet bulb sock or assure that it is clean and dry). Avoid direct sunlight or drafts when making comparisons.
- e. Accuracy is $\pm 1^{\circ}\text{F}$. If any bulbs are not within this accuracy range, mark them to avoid further use.

2.1.2 Use

- a. The psychrometer is used for determining the ambient temperature, relative humidity, and dewpoint.
- b. Assure the sock of the wet bulb is relatively clean prior to use.
- c. Saturate the sock with tap water.
- d. Whirl the sling psychrometer through the air (away from the body) in the immediate area of the surface preparation or painting operation for approximately 20 seconds and note the wet bulb reading.

- e. Repeat the process until two or more consecutive wet bulb readings are the same. Record the wet and dry bulb temperatures at that time.
- f. Plot the dry and wet bulb readings in the U.S. Weather Bureau Tables in accordance with 2.4 to determine the relative humidity and dewpoint.

2.2 Electric Psychrometer

Description: this instrument consists of wet and dry bulb thermometers in a plastic case with battery-operated fan.

2.2.1 Calibration

- a. Psychrometers are factory calibrated. Field calibration is not necessary.
- b. The thermometers should maintain their accuracy under normal use.
- c. Verify the accuracy of the thermometers at least monthly.
- d. Compare three thermometers (remove the wet bulb sock or assure that it is clean and dry). Avoid direct sunlight or drafts when making comparisons.
- e. Accuracy is $\pm 1^{\circ}\text{F}$. If any bulbs are not within this accuracy range, mark them to avoid further use.

2.2.2 Use

- a. The psychrometer is used for determining the ambient temperature, relative humidity, and dewpoint.
- b. Assure that the sock of the wet bulb is relatively clean prior to use.
- c. Saturate the wet bulb sock with tap water.
- d. Use instrument in immediate area of surface preparation or painting application.
- e. Start the fan of the instrument and observe the wet bulb thermometer.
- f. The instrument should stabilize at the appropriate reading within approximately 2 minutes. Stabilization occurs when the wet bulb thermometer reaches its lowest temperature and remains constant. After a time, it may begin to rise again.
- g. Record both the wet and dry bulb temperatures when the wet bulb reaches its stabilization point.
- h. Plot the wet and dry bulb temperatures in the U. S. Weather Bureau Tables in accordance with 2.4 to determine the relative humidity and dewpoint.

2.3 Surface Temperature Thermometer (PTC Surface Temperature Thermometer)

Description: this instrument is a dial thermometer with magnetic mounts and a glass-enclosed face.

2.3.1 Calibration

- a. Thermometers are factory calibrated. Field calibration is not necessary, but verify the accuracy of thermometers at least monthly.
- b. Compare the thermometer reading with that from a psychrometer. Lay the thermometer on the end of the psychrometer, cover with paper to eliminate drafts, and allow to stabilize approximately 2 minutes.
- c. Accuracy is ± 2 percent of the full scale range. If any of the thermometers are not within this accuracy range, mark them to avoid further use.

2.3.2 Use

- a. The surface temperature thermometer is used for determining the temperature of a substrate.
- b. Assure that the tab of the sensing element on the backside is in the slot of the encasing steel ring.
- c. Attach the thermometer to the surface so that the bimetallic sensing element is against the surface being measured.
- d. Allow the thermometer to remain on the substrate approximately 2 minutes to stabilize.
- e. Lightly tap the glass on the face of the instrument to ensure the indicator is free.
- f. View the instrument perpendicularly to avoid erroneous readings due to parallax.

2.4 U.S. Weather Bureau Tables

Description: this is a booklet which contains relative humidity and dewpoint tables compiled by the U.S. Weather Bureau.

2.4.1 Use

- a. The Weather Bureau Tables are used to determine the relative humidity and dewpoint temperatures associated with a corresponding set of dry and wet bulb temperatures.
- b. Use the relative humidity and dewpoint tables corresponding to 30 inches barometric pressure, unless alternative current Weather Bureau barometric pressure information is available.

- c. Turn to the dewpoint chart (at 30 inches barometric pressure) and find the dry bulb temperature reading in the left column, entitled "Air Temperature t."
- d. Locate the depression of the wet bulb thermometer (t-t') across the top line. The depression is the number which results when the wet bulb reading is subtracted from the dry bulb reading.
- e. Plot the intersection of the numbers in "c" and "d." This represents the dewpoint in degrees Fahrenheit.
- f. Repeat the above procedure using the relative humidity tables at the same barometric pressure.

2.5 Hypodermic Needle Pressure Gage (Ingersoll-Rand, Clemtex)

Description: this instrument is a dial type pressure gage with clear plastic face onto which a hypodermic needle is attached.

2.5.1 Calibration - The needle gage is factory calibrated. Field calibration is not necessary.

2.5.2 Use

- a. The hypodermic needle pressure gage is used for determining air pressure at the blast nozzle.
- b. Take a reading as close to the nozzle as possible with abrasive flowing.
- c. Insert the needle through the hose in the same direction as abrasive flow.
- d. The air pressure will be registered by the pointer on the scale.

CAUTION: Designed for use on blast hose only. Use on other air line hoses may result in leaks in hose.

2.6 Surface Profile Comparator (Keane-Tator Surface Profile Comparator)

Description: this instrument consists of a battery-operated flashlight with a 5X magnifier used in combination with a five-petal disc with different roughnesses. Discs are available for surfaces blast cleaned with sand, shot, or grit.

2.6.1 Calibration

- a. Comparator discs are factory calibrated. Field calibration is not necessary.
- b. The discs are used for comparisons only. Calibration verification is not required as the profile on the disc cannot change.

- c. Reject discs that are marred or scratched to such an extent to make them difficult for use in comparisons.

2.6.2 Use

- a. The comparator is an instrument for visually determining the surface profile of blast cleaned steel.
- b. The first number of each section of the disc represents the roughness in mils; the letter designation represents the abrasive(S-Sand, G/S-Steel Grit, SH-Shot, and the last number (70 or 76) represents the year that the master disc was formed.
- c. Use the reference disc that represents the blasting abrasive used.
- d. Attach the disc to the magnetic ring of the magnifier.
- e. Place the entire unit directly on the blast-cleaned surface.
- f. The profile is determined to be equivalent to the section of the disc or between two sections of the disc which most closely represent the roughness of the blast-cleaned substrate.

2.7 Wet Film Gage (Nordson Wet Film Gage) Description: This instrument is a notched gage with progressively deeper steps.

2.7.1 Calibration

- a. Wet film gages are factory calibrated. Field calibration is not necessary.
- b. Reject instruments if any coating residue has built up on the steps. (Such instruments can be reused after cleaning.)

2.7.2 Use

- a. The wet film gage is an instrument for determining the wet film thickness of applied coatings. The wet film thickness, when multiplied by the percent solids by volume of the coating material, represents the theoretical dry film thickness.
- b. Assure that the base and "steps" of the instrument are cleaned of all residual coating prior to each use.
- c. Press the instrument firmly into the coating down to the substrate as soon after application as possible, and carefully remove.
- d. The wet film thickness is read as being between the last wetted step and the next adjacent higher dry one. This determination can be made by either counting the dimples left in the coating itself, or by noting the coating adhering to steps of the instrument.

- e. When taking readings on pipe or other curved surfaces, the instrument should be placed lengthwise along the curve rather than across its width, as the curve will cause irregular wetting of the instrument.
- f. Readings should be taken on areas that are relatively flat, smooth, and free of surface imperfections.
- g. Readings intended to be representative of an entire surface should not be recorded over runs, sags, or other heavy areas.

CAUTION: Instrument designed for use on slow-drying coatings. Use on fast-drying lacquers is not recommended.

2.8 Magnetic Pull-Off Dry Film Thickness Gages (Mikrotest, Inspector Thickness Gage, Positest)

Description: this instrument is a "banana" type gage with retractable magnet and a graduated scale dial.

2.8.1 Calibration

- a. Calibrate the instruments prior to, during, and after each use in accordance with the requirements of SSPC-PA2-82, "SSPC Method for Measurement of Dry Paint Thickness with Magnetic Gage."
- b. Calibrate using National Bureau of Standards thickness plates.
- c. Choose the thickness standard(s) that are representative of the expected dry film thickness range to be measured.
- d. Place the nose of the instrument on the selected thickness plate and rotate the dial forward until the magnet makes solid contact.
- e. Slowly retract the dial until the magnet breaks contact with the plate.
- f. If the numerical reading on the dial scale ring does not correspond with the thickness plate, calibration is necessary.
 - f.1 Inspector Gage--Insert screwdriver into the side of the instrument and hold firmly. Rotate the dial of the instrument until the desired thickness (corresponding to the calibration thickness plate) lines up with the hairline.
 - f.2 Positest--Same as above except remove the small cover from side of instrument and insert a ballpoint pen into one of the exposed holes.
 - f.3 Mikrotest Model 102--Same as f.1 above except that a two-prong calibration tool is used instead of a screwdriver or ballpoint pen.
 - f.4 Mikrotest II or III--Turn scale dial until the small hole on the dial lines up with the hole located in the "O" of the word "Mikrotest." Insert a paper clip through both holes. This keeps

the scale from moving when the dial is turned. Approximate the distance that the true thickness (shim thickness) is away from the thickness registered by the gage. Line up the holes, insert the paper clip and turn the dial in the direction of the desired number by the estimated distance. For example, if the gage is used on a 10-mil shim, but it registers 14 mils, the true thickness of 10 mils is approximately 1/4 inch to the left of the gage reading of 14 mils. Line up the holes, insert the paper clip, and turn the dial approximately 1/4 inch counterclockwise.

- g. Take more readings and readjust the instrument accordingly until the thickness shown on the dial scale ring consistently corresponds to that of the calibration plate.
- h. Check the instrument on other calibration plates to determine the range of accuracy.
- i. With the calibrated instrument, take a minimum of 10 readings on the bare blast-cleaned substrate. The average of the numerical values obtained is called the base reading. The base reading is a correction factor that must be subtracted from subsequent thickness readings to obtain the true dry film thickness above the peaks of the profile. For example, if thickness readings taken with the calibrated Mikrotest show 4 mils and the base reading of the blast cleaned, uncoated substrate is 1/2 mil, the actual thickness of the coating above the peaks of the profile is 3-1/2 mils.
- j. The base reading is considered a constant and need only be determined at the beginning of the project. This value will not change provided the same or similar blasting apparatus and abrasive size and type are used.
- k. If thickness readings are found to be outside the range for which the instrument was calibrated, repeat the calibration process in that thickness range.

2.8.2 Use

- a. The pull-off gages measure the dry film thickness of nonmagnetic coatings above the peaks of the profile of ferrous substrates.
- b. Care should be taken that the magnet of the instrument is clean of coating residue, magnetic filings, or any other contaminants.
- c. Calibrate the instrument before use and verify periodically during use.
- d. Hold the instrument firmly to the surface and turn the dial forward until the magnet makes solid contact with the substrate.
- e. Retract the dial slowly and smoothly until the magnet breaks contact with the surface. Assure that all rotation is immediately stopped when the magnet breaks contact.

- f. The thickness is read as the number on the scale which lines up with the hairline of the instrument. Be sure to subtract the magnetic base reading from that value to obtain the true coating thickness.

2.9 Positector 2000

Description: this instrument is a pocket-sized gage which operates on a magnetic flux principle and displays coating thickness on a digital readout.

2.9.1 Calibration

- a. Calibrate the instrument prior to, during, and after each use using National Bureau of Standards thickness plates.
- b. Choose the thickness standards that are representative of the expected dry film thickness range to be measured.
- c. Place the Positector contact probe on one of the thickness plates (allow the reading to stabilize) and read the digital indicator. To avoid altering the reading, remove the gage sharply from the surface. The reading will remain until the next measurement is taken.
- d. If the numerical reading on the digital indicator does not correspond with the thickness plate, calibration is necessary. Calibration is performed by the "push-to-turn" button located on the left side of the instrument housing. Remove the instrument from the thickness plate (the "push-to-turn" button should never be turned while instrument is in contact with the thickness plate). Depress the button and turn clockwise or counterclockwise until the reading on the digital indicator corresponds to the thickness plate.
- e. Take more readings and readjust the instrument accordingly until the thickness shown on the digital indicator consistently corresponds to that of the calibration plate.
- f. Check the instrument on other calibration plates to determine the range of accuracy.
- g. With the calibrated instrument, take a minimum of 10 readings on the bare blast-cleaned substrate. The average of the numerical values obtained is called the base reading. The base reading is a correction factor that must be subtracted from subsequent thickness readings to obtain the true dry film thickness above the peaks of the profile. For example, if thickness readings taken with the calibrated Positector show 4 mils and the base reading of the blast-cleaned uncoated substrate is 1/2 mil, the actual thickness of the coating above the peaks of the profile is 3-1/2 mils.
- h. The base reading is considered a constant and need only be determined at the beginning of the project. This value will not change provided the same or similar blasting apparatus and abrasive size and type are used.

- i. If thickness readings are found to be outside the range for which the instrument was calibrated, repeat the calibration process in that thickness range.

2.9.2 Use

- a. The Positector measures the dry film thickness of nonmagnetic coatings above the peaks of the profile of the ferrous substrate.
- b. Care should be taken that the magnet of the instrument is clean of coating residue, magnetic filings, or any other contaminants.
- c. Calibrate the instrument before use and verify periodically during use.
- d. Hold the instrument firmly and squarely to the surface while taking a reading. The thickness reading is the value shown on the digital indicator after it stabilizes. The value can be read while the instrument is still in contact with the surface, or the instrument can be sharply removed from the surface and the value will remain on the digital indicator until the next reading is taken.
- e. Subtract the magnetic base reading of the bare steel substrate (obtained during calibration) from the digital value to achieve the true coating thickness above the peaks of the profile.

2.10 Magnetic Flux Dry Film Thickness Gage -- Two Prong Type -- Elcometer 101 Model

Description: this instrument is a pocket-sized, two prong gage which uses a permanent magnet.

2.10.1 Calibration

- a. Calibrate the instrument prior to, during, and after each use using plastic shims. Verification of the stated thickness of the shims may be required by the use of a micrometer.
- b. Choose the plastic shim thickness that is representative of the expected dry film thickness to be actually measured.
- c. Place one of the range selected plastic shims on a bare uncoated portion of blast cleaned steel, then place the instrument's two base prongs firmly on the shim.
- d. Depress the small button to release the scale pointer. When the pointer comes to rest and its position on the meter scale does not correspond with the thickness of the plastic shim, calibration is required.
- e. Calibration is performed by slowly turning the large knurled button on the instrument's side until the instrument reading corresponds to the plastic shim thickness.

2.10.2 Use

- a. The Elcometer Model 101 is a magnetic flux type dry film thickness gage using the properties of a permanent magnet to determine the dry film thickness of nonmagnetic coatings above the peaks of the profile of ferrous substrates.
- b. Calibrate the instrument prior to and during each use. The instrument must be used in the same physical orientation, i.e., sideways, upside down, etc., in which it was calibrated. Any change in the physical orientation during use will necessitate recalibration in the same position and orientation.
- c. Care must be taken that the two prongs in the base of the instrument are clean and free of any coating residue, magnetic filings, or any other contaminants.
- d. Hold the instrument's base prongs firmly to the coated surface and depress the small button located on the side, keeping the button depressed until the scale pointer has stabilized. Release of the button while maintaining prong-to-surface contact will lock the pointer at the indicated thickness reading.
- e. Do not take readings within 1 inch of edges or too close to large masses of steel or operating electric welding equipment.

2.11 Magnetic Flux Dry Film Thickness Gage -- Electronic -- (Verimeter, Minitector, GE Type B)

Description: these instruments are fixed probe Type 2 gages as described by the SSPC-PA2-82.

2.11.1 Calibration

- a. Calibrate the magnetic flux instruments prior to and during each use.
- b. Calibrate in accordance with SSPC-PA2-82 "SSPC Method for Measurement of Dry Paint Thickness with Magnetic Gages."
- c. Calibrate using the plastic shim method only.
- d. Choose plastic shims in the same thickness range as that expected to be measured. Thickness of the shim can be verified by using a micrometer.
- e. Turn the instrument on and allow it to warm up approximately 2 minutes.
- f. Turn the selector knob to the scale that covers the expected thickness range.

- g. Bring the probe of the instrument in contact with the bare blast-cleaned substrate and adjust the "zero" knob until the pointer on the meter scale indicates "0." Take a few readings to assure that the instrument is properly adjusted to "0."
- h. Place the plastic shim of known thickness on the blast-cleaned substrate. Firmly press the probe on this shim.
- i. Adjust the calibration knob (labeled "gain" on Verimeter; "sensitivity" on Minitector) until the pointer of the meter scale indicates the known shim thickness.
- j. Repeat the "zero" set and calibration processes until both the substrate base reading and the shim reading are adjusted properly.
- k. When taking readings, coating thickness is indicated directly on the meter scale.

2.11.2 Use

- a. The magnetic flux dry film thickness gages are used for determining the dry film thickness of nonmagnetic coatings above the peaks of the profile of ferrous substrates.
- b. Calibrate the instruments prior to and during each use.
- c. Firmly place the probe of the instrument on the coated surface.
- d. Do not take readings within 1 inch of edges or too close to great masses of steel or operating electric welding equipment.
- e. The thickness is represented by the indicator of the meter scale. Be sure to view the scale perpendicularly to avoid erroneous readings due to parallax.

2.12 Destructive Optical Thickness Gage (Tooke Gage)

Description: this unit consists of a 50X illuminated microscope with three cutting tips of different angles.

2.12.1 Calibration

- a. The Tooke Gage is factory calibrated. Field calibration is not necessary.
- b. If the accuracy of a cutting tip is questioned, compare the thicknesses determined by all three cutting tips in the same location.
- c. Alternatively, compare the thickness determined by the Tooke Gage with that of a magnetic gage calibrated to National Bureau of Standards thickness plates.

- d. If the readings do not agree within reason, introduce another magnetic gage. Be certain to take readings in exactly the same location.
- e. If the tip appears to be inaccurate, mark it to prevent further use.

2.12.2 Use

- a. The optical dry film thickness gage uses a 50X illuminated microscope in conjunction with a microscopic incision made through the coating. This provides for the direct observation of a cross-section of the coating to determine thickness.
- b. Make a reference benchmark on the coated surface with the marker supplied in the instrument or a pencil.
- c. Make an incision with one of the cutting tips through the coating in the location of the benchmark down to the substrate. It is important to remember which tip is used.
- d. View the incision through the microscope. Coating will be visible on both sides of the substrate. One side will appear to have a smoother edge at the benchmark than the other. Evaluate only the smoother side of the coating.
- e. Line up the reticle of the microscope across the incision and count the number of divisions of the coating from the substrate interface outward to the benchmark. Each division is equivalent to one mil if the 1X tip is used, 1/2 mil if the 2X tip is used, and 1/10 mil if the 10X tip is used.
- f. The thickness reading is the approximate average of readings obtained across the length of the scribe.
- g. The thickness of individual coats in a multi-coat system can be determined by the same method.

2.13 Low Voltage Holiday Detectors (K-D Bird Dog, Tinker & Razor M-1)

Description: this unit consists of a sponge connected to a low voltage power supply. When the wetted sponge crosses a coating holiday, the circuit is closed and a buzzer sounds.

2.13.1 Calibration - The holiday detectors are factory calibrated. Field calibration is not necessary.

2.13.2 Use

- a. The wet sponge holiday detector is used for locating pinholes, holidays, and in some cases, very thin moisture permeable areas in coatings up to 20 mils thick.
- b. Securely fasten the ground wire of the instrument to a bare section of the coated steel. If necessary, cut through the coating to make good contact.

- c. Saturate the sponge with water and, for heavier coatings, a wetting agent (soap, photographic development fluid).
- d. Brush the sponge across the entire surface in a systematic overlapping method.
- e. If the signaling device detonates, turn the sponge on end to pinpoint the defect.
- f. Circle the defect with an acceptable marking device for repair.
- g. Instruments with variable voltage shall be set not higher than 67-1/2 volts.

INDEX

A

Abrasives -- 4-21
Abrasive Blast Cleaning -- 4-7
Abrasive Breakdown Characteristics -- 4-22
Air Compressor -- 4-8
Air Hose -- 4-9
Airless Equipment Adjustment -- 5-24
Airless Spray Paint Application -- 5-20
 Advantages -- 5-20
 Disadvantages -- 5-20
Alkyd Paints -- 3-2
Alligatoring -- 7-3
Ambient Conditions -- 6-3, 7-7
Application Instruments -- 5-5, 5-6
Atmospheric Conditions -- 7-7

B

Back-to-Back Angles -- 7-12
Basic Corrosion Cell -- 2-2
Bituminous Coatings (Cold Applied) -- 3-7
Blast Cleaning Efficiency Checklist -- 4-18
Blast Cleaning Equipment and Techniques -- 4-8, 4-19
Blast Hose -- 4-12
Blast Nozzle -- 4-12
Blast Pot -- 4-11
Bleeding -- 7-11
Blistering -- 7-4
Blushing -- 7-11
Brushing -- 5-5
Brush Versus Spray -- 5-1

C

Catalyzed Epoxy Coatings -- 3-5
Cathodic Protection -- 2-14
Chalking -- 7-2
Checking -- 7-2
Chlorinated Rubber Paints -- 3-9
Choice of Paint Application System -- 5-8
Cleanliness of the Abrasive Material -- 4-24
Coal Tar Epoxy -- 3-6
Coating Thickness -- 6-10, 6-12
Conventional (Air) Spray Painting -- 5-8
Conventional Spray Gun Adjustment -- 5-11
Corrosion Potentials and the Direction of Galvanic Effects -- 2-9
Corrosion Resistant Materials -- 2-12
Cracking -- 7-2
Cratering -- 7-11

D

Design -- 7-12
Determination of Dry Film Thickness -- 6-12
**Determination of Surface Preparation,
Cleanliness, and Profile -- 6-5**
Discoloration -- 7-4
Discontinuous Areas -- 7-13
Drying Oil (Oleoresinous Paints) -- 3-1

E

Edges -- 7-12
Electrochemical Corrosion -- 2-1
Equipment and Materials -- 5-9, 5-22
Erosion -- 7-2
Evaluating Cleanliness Between Coats -- 6-23
**Evaluation of Compressed Air Cleanliness
and Surface Preparation Equipment -- 6-4**

F

Flaking and Sealing -- 7-6

G

Galvanic Action -- 2-8

H

Hand Tool Cleaning -- 4-3
Holidays -- 7-11

I

Importance of Surface Preparation -- 4-1
Inhibitors -- 2-14
Inspection of Application Equipment and Techniques -- 6-9
Inspection Sequence -- 6-2
Intercoat Delamination -- 7-6
Inside Corners -- 7-13

J

K

L

Lifting -- 7-11

M

Measuring Air Supply at the Nozzle -- 5-10

Measurement of Wet Film Thickness -- 6-10

Methods of Surface Preparation -- 4-3

Micro-Organism Failure -- 7-3

Mixing -- 5-3

Moisture/Oil Separators and Blast Machine -- 4-11

Mudcracking -- 7-3

N

O

Oil Base Paints -- 3-1

Operational Checks -- 5-16

Orange Peeling -- 7-11

Overspray -- 7-9

P

Paint Mitt -- 5-6

Paint Storage -- 5-1

Paint Viscosity -- 5-2

Peeling -- 7-11

Pinhole and Holiday Testing -- 6-23

Pinholes -- 7-10

Pinpoint Rusting -- 7-4

Power Tool Cleaning -- 4-4

Pre-Surface Preparation Inspection -- 6-2

Preventive Maintenance -- 5-25

Protective Coatings -- 2-11

Q

Quality Concerns During Blast Cleaning -- 4-23

Quality of Air Supply -- 4-24

R

Rollers -- 5-6

Runs or Sags -- 7-12

S

Safety -- 4-14, 6-1
Shape -- 4-22
Size and Hardness -- 4-20
Skip Welding or Stitch Welding -- 7-12
Solvent Cleaning -- 4-3
Spatter Coating -- 7-10
Spray Gun Techniques -- 5-13
Spray Painting - General Methods and Techniques -- 5-7
Spray Pattern and Gun Problems -- 5-19
Spray Techniques -- 5-25
Standards of Cleanliness -- 4-25
Steam Cleaning -- 4-3
Storage -- 5-1
Sulfide Discoloration -- 7-4
Surface Preparation -- 4-1

T

Techniques for Corrosion Control and Prevention -- 2-11
Tests for Adhesion -- 6-26
Tests for Cure -- 6-26
Thinning -- 6-9

U

Undercutting -- 7-7

V

Vinyl -- 3-2
Visual Standards -- 4-27

W

Water Blasting -- 4-5
Welds -- 7-13
Witnessing Coating Mixing and Thinning -- 6-9
Wrinkling -- 7-3

X

Y

Z

USA-CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-INS-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWN-R
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-EC
ATTN: DAEN-ECC
ATTN: DAEN-ECE
ATTN: DAEN-ECR
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RH
ATTN: DAEN-ZCE
ATTN: DAEN-ZCF
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM
ATTN: DAEN-ZCZ

FESA, ATTN: Library 22060
ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library (41)

US Army Engineer Divisions
ATTN: Library (14)

US Army Europe
AEAEN-ODCS/Engr 09403
ISAE 09081
V Corps
ATTN: DEH (11)
VII Corps
ATTN: DEH (15)
21st Support Command
ATTN: DEH (12)
USA Berlin
ATTN: DEH (11)
USASSETAF
ATTN: DEH (10)
Allied Command Europe (ACE)
ATTN: DEH (3)

8th USA, Korea (19)
ROK/US Combined Forces Command 96301
ATTN: EUSA-HMC-GFC/Engr

USA Japan (USARJ)
ATTN: AJEN-DEH 96343
ATTN: DEH-Honshu 96343
ATTN: DEH-Okinawa 96331

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10966
ATTN: Facilities Engineer
ATTN: Dept of Geography &
Computer Science
ATTN: DSCPER/MAEN-A

AMMRC, ATTN DRXMR-WE 02172

USA ARRCOM 61299
ATTN: DRCIS-RI-I
ATTN: DRSAR-IS

AMC - Dir., Inst., & Servc
ATTN: DEH (23)

DLA ATTN: DLA-WI 22314

DNA ATTN: NADS 20305

FORSOM
FORSOM Engr, ATTN: AFEN-DEH
ATTN: DEH (23)

HSC
ATTN: HSLO-F 75234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch. Instl. Div
ATTN: Facilities Engineer (3)

MDW, ATTN: DEH (3)

NTMC
ATTN: MTNC-SA 20315
ATTN: Facilities Engineer (3)

NARADCOM, ATTN: DRDNA-F 01760

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-DEH
ATTN: DEH (19)

TSARCOM, ATTN: STSAS-F 63120

USACC, ATTN: Facilities Engr (2)

WESTCOM
ATTN: DEH, Ft. Shafter 96858
ATTN: APEN-IM

SHAPE 09055
ATTN: Surv. Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

FORT BELVOIR, VA 22060 (7)
ATTN: Canadian Liaison Office
ATTN: Water Resources Support Ctr
ATTN: Engr Studies Center
ATTN: Engr Topographic Lab.
ATTN: ATZA-DTE-SU
ATTN: ATZA-DTE-EN
ATTN: R&D Command

CRREL, ATTN: Library 03755

WES, ATTN: Library 39180

HQ, XVIII Airborne Corps
and Fort Bragg
ATTN: AFZA-FE-EE 28307

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Morton AFB, CA 92409
ATTN: AFRCE-MX/DEE

AFESC, Tyndall AFB, FL 32403

NAVFAC
ATTN: Engineering Command (7)
ATTN: Division Offices (6)
ATTN: Naval Public Works Center (9)
ATTN: Naval Civil Engr Lab. (3)

ATTN: Library, Code L08A NCEL 93043

Defense Technical Info. Center 22314
ATTN: DDA (2)

Engr Societies Library, NY 10017

Natl Guard Bureau Instl. Div 20310

US Govt Print Office 22304
Receiving Sect/Depository Copies (2)

US Army Env. Hygiene Agency
ATTN: HSHB-E 21010

National Bureau of Standards 20899

END

DTIC

7-86